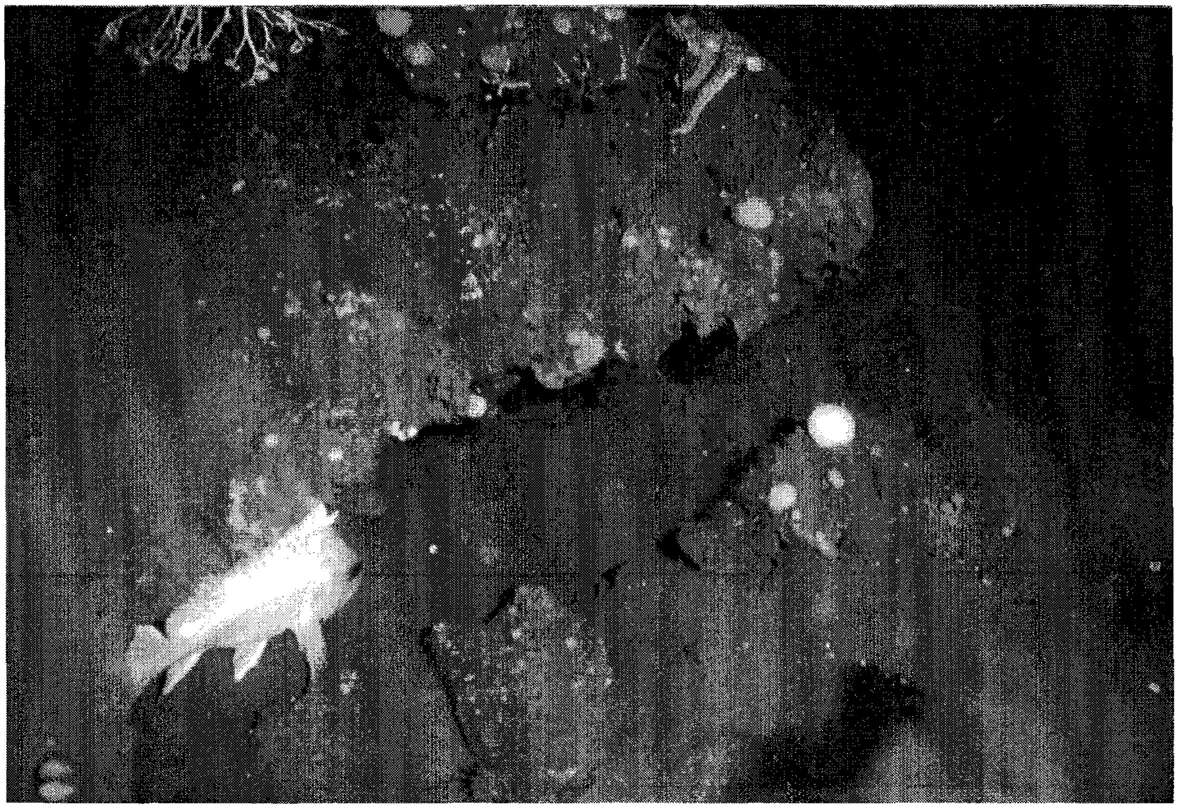
WORKSHOP PROCEEDINGS

Applications of Side-Scan Sonar and Laser-Line Systems in Fisheries Research

Coast Bastion Inn
Nanaimo, British Columbia, Canada
January 20, 1994



SPECIAL PUBLICATION NO. 9

Alaska Department of Fish and Game
Commercial Fisheries Management
and Development Division
Juneau, Alaska

March 1995

State of Alaska
Tony Knowles, Governor

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PREFACE

The collection of abstracts in this volume represents the proceedings of a workshop held on January 20, 1994, at the Coast Bastion Inn, Nanaimo, British Columbia, Canada, directly following the 8th Western Groundfish Conference. Funding for the workshop was provided by the West Coast National Undersea Research Center, and sponsorship was provided by the Alaska Department of Fish and Game. The moderators gratefully acknowledge the following persons for their help during the workshop and their associated activities: Dr. Ray Highsmith and David Doudna, WCNURC, Greg Cailliet, Rick Starr, Jan Straley, and Mary Yoklavich. The moderators would also like to thank the organizing committee of the 8th Western Groundfish Conference from the Pacific Biological Station, Department of Fisheries and Oceans, for their support of our workshop: Rick Stanley, Lynne Yamanaka, Debra Murie, Max Stocker, Judy Stolz, Carol Roy, and Bruce Leaman.

The workshop's primary purpose was to bring together marine fishery biologists, marine geologists, and technology representatives to discuss the availability, applications, and limitations of side-scan sonar and laser-line technologies as it relates to the investigation of marine fish habitats. A total of 14 presentations were made. In all, we received abstracts and extended abstracts for 13 of the presentations: 3 related to fisheries applications, 3 related to geology and fish habitats, and 7 that were more technology related. The intent of publishing these abstracts is to provide the reader with a source for locating more detailed information on the successful application of side-scan and laser-line technology in fisheries research.

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Moderators

THE USE OF SIDE-SCAN SONAR FOR LANDSCAPE APPROACHES TO HABITAT MAPPING

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Peters and Cross (1991) define habitat as "the structural component of the environment that attracts organisms and serves as a center of biological activity." They note there has been great difficulty determining at what scale environmental factors affect the distribution and abundance of organisms; i.e., what factors at which scales do organisms respond so that one can determine their activities and range? Distributional patterns of fishes and macrocrustaceans can be found at a variety of scales. For example, in the northwest Atlantic off the northeastern coast of the United States, regional or large-scale patterns in distribution follow isotherms and isobaths (Colvocoresses and Musick 1984; Gabriel 1992). At scales of meters to tens of meters, these same organisms have significant associations with microtopographic features, such as shell, biogenic depressions, and sand wave crests (Auster et al. 1991, unpublished data). At smaller scales of centimeters to meters, post-larval silver hake respond to the density of amphipod tubes (unpublished data).

Any structural component in the environment occurs within a *patch*, e.g., a water mass or a mussel bed, which is typically considered to be homogeneous internally and discrete from adjacent patches (Pickett and White 1985). Patches are often defined in a convenient manner so that one can relate it to the organisms studied and the questions of interest; for example, what is the abundance of elasmobranchs on Georges Bank, or what density of juvenile lobsters occurs in a patch of cobble? However, we often are restricted in our sampling of the marine environment by the technology we choose to utilize and make available. Figure 1 depicts a line transect through *patches* of habitat of unequal size but of identical type. The transect line represents the path of camera sled or trawl. Regardless of the type of sampling gear, data produced from transects which sample patches of unequal or unknown size may exhibit a very high degree of variability compared to samples taken in discrete patches of equal or known size. This is a simple example of our inability to easily sample subtidal habitats in an ecologically meaningful way when using traditional methods. Interest in heterogeneity in the environment has expanded the study of *landscape ecology* and the influence of *patchiness* at multiple scales on the distribution and abundance of species (Urban et al. 1987; Kotliar and Wiens 1990). These types of studies have traditionally been conducted in terrestrial habitats where mapping of landscape features, and subsequent sampling, are more easily conducted.

We have initiated a study that will look at the influence of landscape features on the distribution and abundance of mobile, benthic fauna, in general, and commercially important species, in particular. The study's major objectives are to

(1) determine if the habitat milieu (sedimentary, biogenic) is static (in seasonal to interannual time frames) or changes over time in a way that affects habitat availability and potential recruitment success; and

(2) determine at which scales variations in landscape features affect the distribution and abundance of mobile organisms.

Side-scan sonar is one of several sampling methods used to determine the spatial distribution of features in the environment. Side-scan sonar records can be used to remotely sense a variety of habitat characteristics. Such characteristics include:

(1) determining coverage of specific sediment types, such as patch size and circularity measures;

(2) measuring habitat complexity, such as the use of acoustic shadows in conjunction with a depth sounder;

(3) enumeration of specific structures, such as lobster burrows; and

(4) documenting changes in distribution and structure over time.

A Differential Global Positioning System (DGPS) provides ship position, and an ultra-short baseline acoustic-tracking system provides slant range and bearing to the side scanned fish. A geographic information system (GIS) is used to manage the georeferenced spatial data.

Side-scan sonar records can be arranged as a mosaic to produce sediment coverage maps of an area. Sediment types are generally validated using grab samples, while boundary areas are easily identified with acoustic records. The GIS can be used to determine the areal extent of specific habitat types, and can store and manipulate replicate surveys and measure temporal changes in habitat type area for sequential surveys.

We are developing methods to produce quantitative indexes of habitat complexity using side-scan records. In particular, we are attempting to develop methods that will take advantage of automated routines in current PC-based image-analysis programs, such as object counting and edge detection. Side-scan records are generally continuous-tone, gray-scale images, such as that seen in Figure 2. The strength of acoustic return declines with distance from the centerline of the record due to attenuation of acoustic energy with increasing path length. The variability of gray-scale tone across regions of similar bottom type in unprocessed records makes automated detection of edges difficult. We have experimented with using acoustic shadows as indexes of habitat complexity; i.e., a shadow length perpendicular to the track line is directly related to vertical relief. Slant-range and speed-corrected records are required so that sizes of shadows and objects are not biased by distance from the track line. By defining a region of interest (ROI) of known area, acoustic records can be subsampled for the total area of shadow and number of shadow units of specific size. While these generalized techniques may be useful for describing differences within specific habitat categories, e.g., sand wave, cobble or boulder, we have not produced a sampling protocol to date that we find acceptable for making comparisons between habitat categories.

Side-scan sonar can be used to census specific classes of objects, such as lobster burrows. Able et al. (1987) used side-scan to census lobster and tilefish burrows. Because they knew burrow occupancy rates, they were able to predict the density. We have used acoustic records to test the role of landscape features on the distribution of lobster burrows. For example, we have assessed the effect of slope angle on the density and patchiness of lobster burrows on an otherwise homogeneous mud-silt bottom in western Long Island Sound. Triplicate lanes were run in 2 areas of greatly different slope, and lobster burrows were identified. We do not have absolute density values from the survey at this time, because records have not yet been corrected for slant range and ship speed, though ship speed was held relatively constant. An arbitrary sample unit, otherwise known as a quadrat, was used to census all records. The 2-term local quadrat variance (TTLQV) method was used to analyze data for spatial pattern. The variances obtained using the TTLQV suggest that a clumping of lobster burrows on steep slopes occurred at ranges of 7–10 sample units (Figure 3). No clumping occurred on shallow slopes at the spatial scale investigated. There were, however, no significant differences in the density of lobster burrows between lanes (ANOVA, $p > 0.05$). Corrected records will be used to refine this analysis and also be used to produce density estimates using standard line-transect techniques.

We have attempted to demonstrate various ecological approaches that can benefit from use of side-scan sonar technology. Integrating side-scan technology into sampling programs that employ traditional or single-scale methods can expand the utility of those methods, provide new insights, and generate new questions related to pattern and process.

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Acknowledgments

This work was supported by the National Oceanic and Atmospheric Administration's (NOAA) National Undersea Research Program, Connecticut Sea Grant, U.S. Geological Survey, and Connecticut Department of Environmental Protection. Dr. Roman Zajac kindly provided access to ship and side-scan equipment for the western Long Island Sound work. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies.

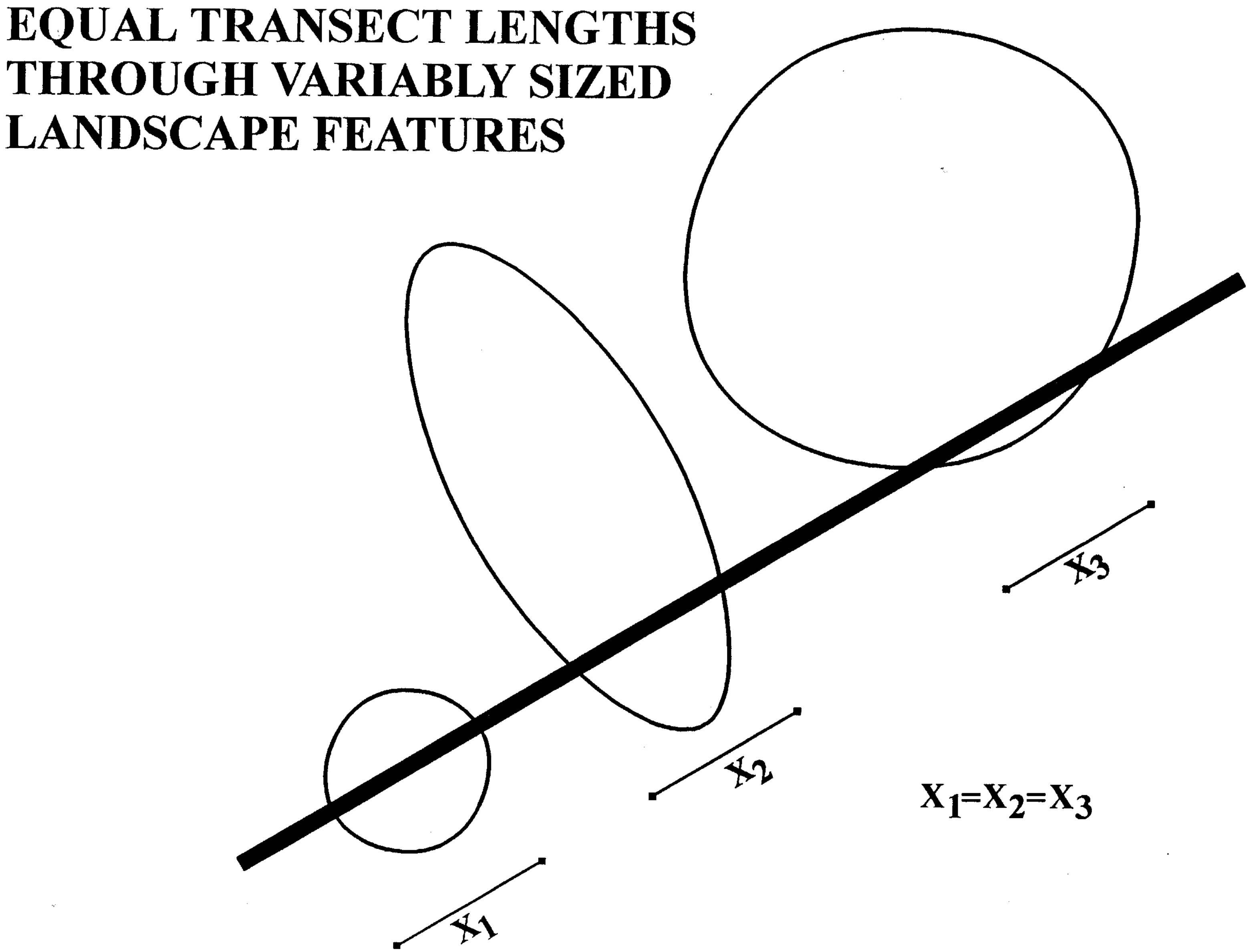


Figure 1. A transect through various sizes of landscape features. Although the transect through each *patch* is of equal length, the samples may exhibit wide variation in abundance estimates due to sampling habitats of unequal size.

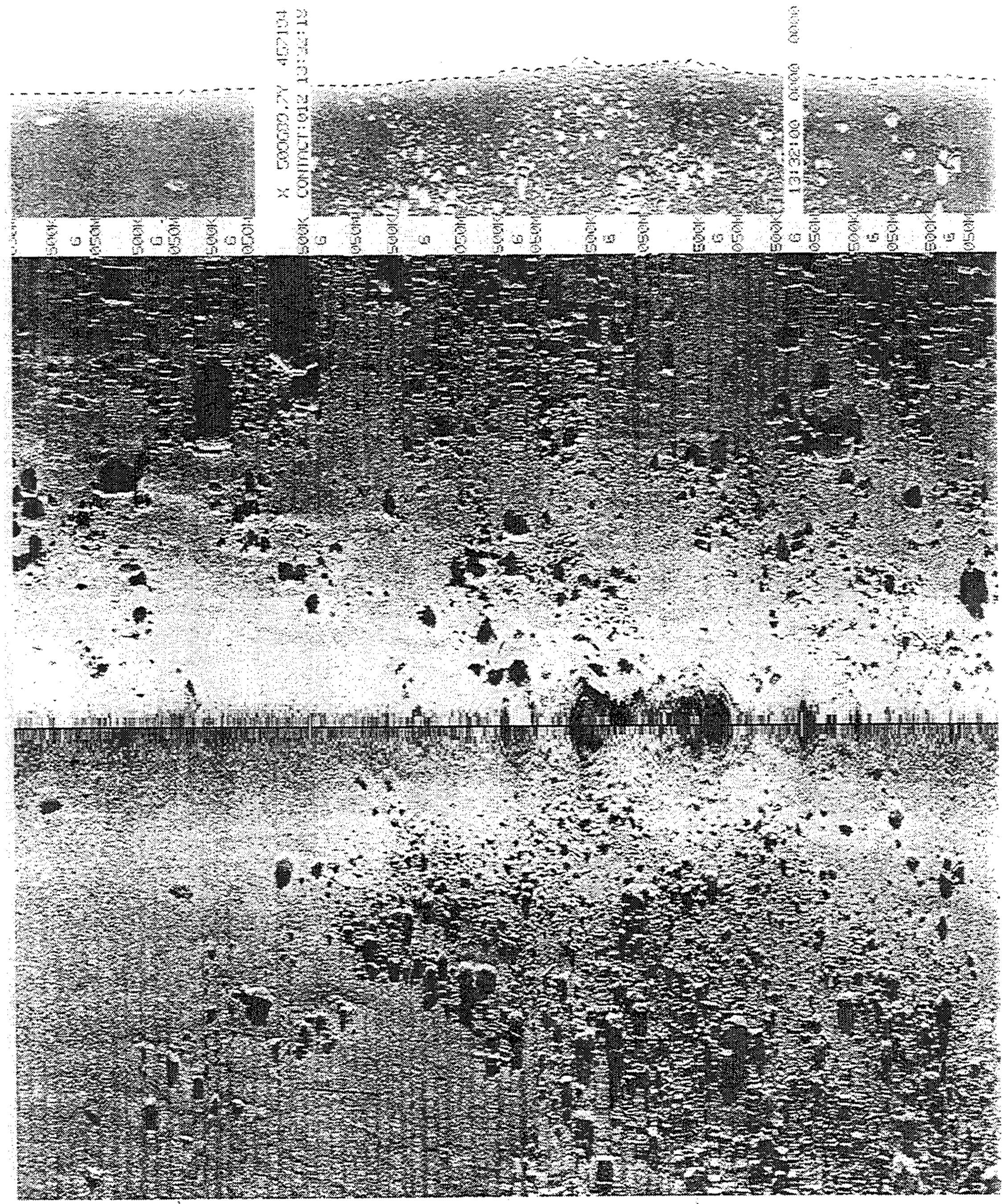
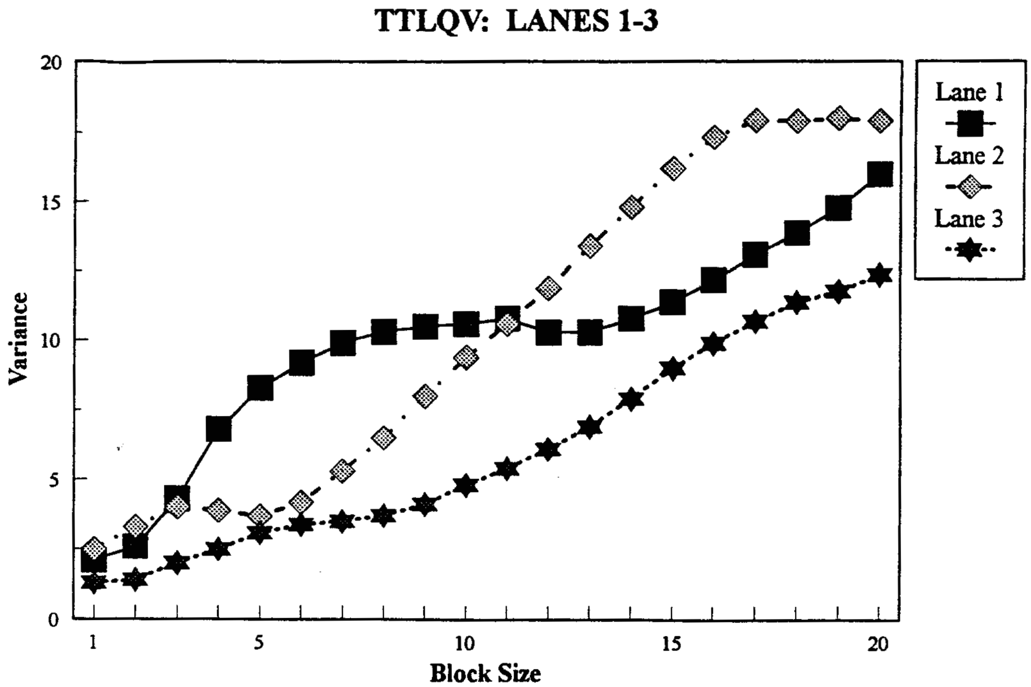


Figure 2. A 500-kHz side-scan sonar record from eastern Long Island Sound showing boulder, rock, cobble, and sand features. This record is a reverse image (acoustic shadows are dark), which aids in interpretation.



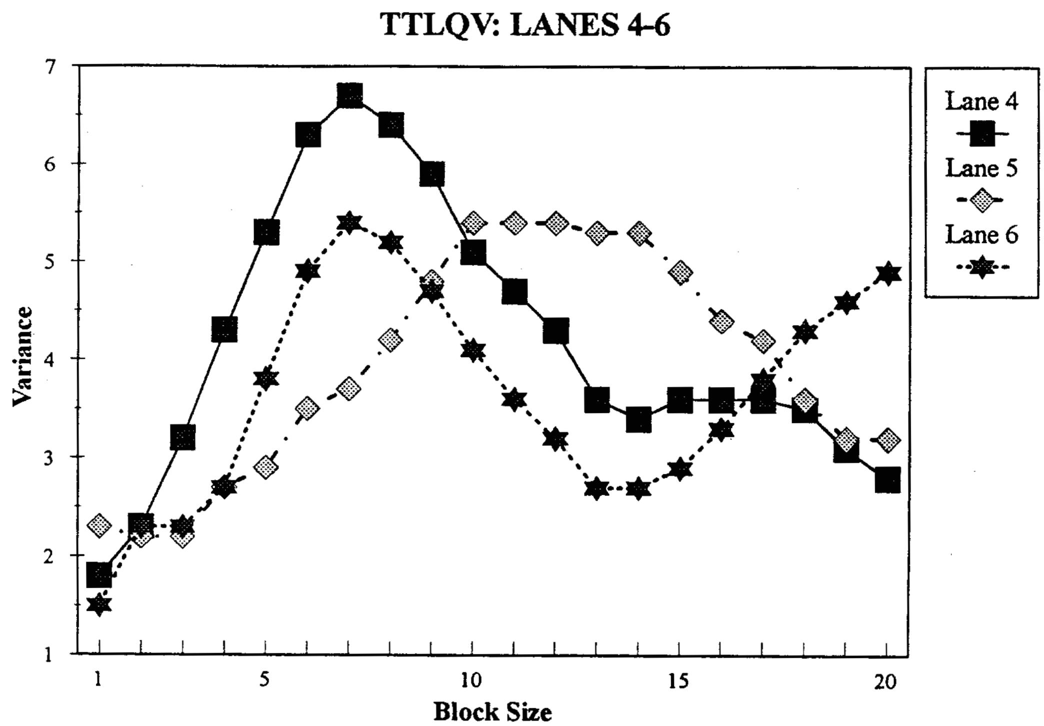


Figure 3. Plots from TTLQV analysis of lobster burrow distribution that show no clumping from lanes on shallow slopes (top) and patchiness at scales of 7–10 sample units across regions of steep slope (bottom).

SIDE-SCAN SONAR AS A TOOL FOR DETERMINATION OF DEMERSAL FISH HABITAT USE PATTERNS ON THE CONTINENTAL SHELF

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Side-scan sonar is a proven, effective tool for the determination of habitat use patterns for selected fishes on the continental shelf. Our primary studies have focused on habitat detection, distribution, abundance, and duration of habitat use by the tilefishes (Family *Branchiostegidae* or *Malacanthidei*) of the genus *Lopholatilus* and *Caulolatilus* along the East Coast of the United States. Together, these studies, and those of others, point out the significance of tilefish burrows and related substrate characteristics that determine, to a large extent, the distribution of these species (Twichell et al. 1985; Grimes et al. 1986; Able et al. 1987a, 1987b). These techniques have also been applied by other investigators (Barans and Stender 1993; Matlock et al. 1991) to extend the geographical range of these observations. Most attempts have used towed side-scan sonar from surface vessels as well as from the NR-1 Navy research submarine in depths from 80 to 300 m over the continental shelf and upper slope. With these techniques, we have confirmed that tilefish burrow densities can reach an average of as high as 2,500/km^2 in the vicinity of Hudson Submarine Canyon and as low as 1–8/km^2 off the coast of Florida. In the latter, two genera, *Lopholatilus* and *Caulolatilus*, have complementary distributions based on analysis of sonograms (Able et al. 1993). The initial hope that tilefish population size could be determined by these sonograms, in part because our observations suggest one tilefish per burrow (Able et al. 1982; Grimes et al. 1986), has proven difficult, because burrows are frequently abandoned as the result of fishing and natural mortality and because they are detectable for many months after the tilefish has left (Grimes et al. 1986; Able et al. 1993). Another confounding factor is our inability to detect burrows smaller than approximately 0.5 m. However, as a result of these studies, we have an improved understanding of the substrate for tilefish habitats and the geomorphology of a portion of the outer continental shelf (Twichell et al. 1985). In all these instances, *in situ* observations with submersibles have proven critical to groundtruthing of sonograms and to a better understanding of burrow construction and detection.

Other ongoing studies are focusing on the habitat use patterns for transforming larvae and recently settled juvenile fishes at an inner continental shelf site off southern New Jersey. Side-scan sonar and subbottom profiling have been essential to the establishment of a Long-Term Ecosystem Observatory (van Alt and Grassle 1992) in depths of approximately 15 m off the coast of southern New Jersey. In particular, these techniques, combined with groundtruthing with SCUBA, have provided an improved understanding of the heterogeneity of this portion of the continental shelf (Twichell and Able 1993). This heterogeneity makes habitat-specific sampling from surface ships less effective, and clearly identifies the need for *in situ* techniques. We are continuing these observations in shallow water to further define the patterns of temporal variation in substrate, especially as they relate to fish settlement habitats. Together, these examples for tilefishes and inner continental shelf habitat provide proof of the effectiveness of combined biological/geological studies, particularly when using acoustic techniques, such as side-scan sonar, when the emphasis is on demersal fish habitats.

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SIDE-SCAN SONAR AS A TOOL FOR FISH HABITAT DETECTION

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High-resolution side-scan sonar is considered for use in fish habitat detection and monitoring. A brief review of the principles of operation and characteristics of side-scan sonar is presented with emphasis on resolving power and its impact on image definition. Selected examples of existing commercial and Navy units are described to illustrate present capabilities of such systems in fisheries research. Current trends in side-scan sonar development and possible areas for improvement are mentioned. Present capabilities of military sonars designed for detection of small objects on the seafloor are believed sufficient for research on certain types of marine animals of interest, but depending on the image definition and area coverage rate required, they are not inexpensive.

INTERPRETATION OF SIDE-SCAN SONAR RECORDS FOR ROCKFISH HABITAT ANALYSIS: EXAMPLES FROM MONTEREY BAY

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Even with decreased landings in recent years, rockfishes are among the most valuable fisheries in California. As their name suggests, many species of rockfishes are associated with rock substrata during most of their lives. Deepwater, rocky outcrops may prove to be important rockfish habitat as local stocks are depleted in shallow, accessible areas. Along the central California coast, several submarine canyons cut into the continental shelf and bring deep water close to shore. We hypothesize that rock outcrops in deep, isolated areas along the steep canyon walls act as a natural harvest refugia for exploited rockfish populations, and allow several species to attain larger sizes and higher abundance than in adjacent, heavily fished areas.

With support from the West Coast National Undersea Research Center, a cooperative project between geologists and fishery biologists was recently undertaken in Monterey Bay. By integrating remote-census, geophysical techniques (e.g., side-scan sonar), *in situ* submersible observations, and fishery information (Figure 1), we have started to evaluate rockfish resources, including species composition, abundance, and distribution, within heavily fished and lightly fished areas of the same depth and microhabitat in the Monterey Bay submarine canyon system and nearby areas. From bottom profiles and navigational data, we have produced accurate, high-resolution bathymetric basemaps. We also have conducted side-scan sonar surveys of the seafloor in several submarine canyons within Monterey Bay and along the central California coast, as well as of shallow rock outcrops historically fished within the bay. Side-scan sonar is the perfect method for differentiating blocks of hard substrata, which appear dark, from surrounding soft sediments because of their greatly different reflectivity (Figure 2). Quality of our side-scan data has ranged from good to excellent; they are primarily dependent on ship speed and bottom topography. Sonographs along each track line were combined with navigational plots to form mosaics of benthic habitat. Plotting the side-scan targets on regional bathymetry, we can quantify the amount of exposed, hard substrata available at depths suitable to rockfishes. Interpretations of the sonographs are verified by observations made from a submersible and integrated with microhabitat information.

From the geophysical surveys and submersible observations, Soquel Canyon is characterized by extensive erosion, with sharp, steep relief and many isolated rock outcrops that provide ideal shelter for large fishes. The most likely rockfish habitat in the headward parts of Monterey, Ascension, and Ano Nuevo Canyons appears in sonographs as well-defined ledges of bedded sedimentary rock. Rockfish habitat at historically fished sites within the Bay comprise large areas of granite and sedimentary outcrops that are surrounded by flat, mud-sand seafloor. Secondary to fish habitat characterization, these results will extend our understanding of regional seafloor geology and provide associated high-resolution maps of the area.

At least 33 species of rockfishes have been identified from preliminary analyses of 80 video-documented, submersible dives. Species composition, size, relative abundance, and habitat specificity are being evaluated. Several distinct assemblages of rockfishes were obvious from initial observations. Large schools of young-of-the-year rockfishes were documented in shallow rock areas of low relief outside submarine canyons, and almost absent at any depth within the canyons. Very specific assemblages of small species, previously considered uncommon, occurred in high numbers over offshore, submerged beach terraces of well-rounded cobble. High numbers of large species (up to 1 m) were closely associated with rock ledges, caves, overhangs, boulders, and broken rock of exposed mudstone interspersed with soft mud on steep sides of canyons. Observations from more heavily fished areas suggest these species are probably protected from excessive harvest on inaccessible, isolated outcrops in the canyons.

We are continuing analyses of the video transects using a geographical information system (GIS) to visualize, map, and analyze these spatially referenced data sets. Integrating side-scan sonar and submersible surveys is very effective in assessing fish assemblages with heterogeneous distributions that are closely associated with deepwater, rocky areas and unavailable to other methods of evaluation.

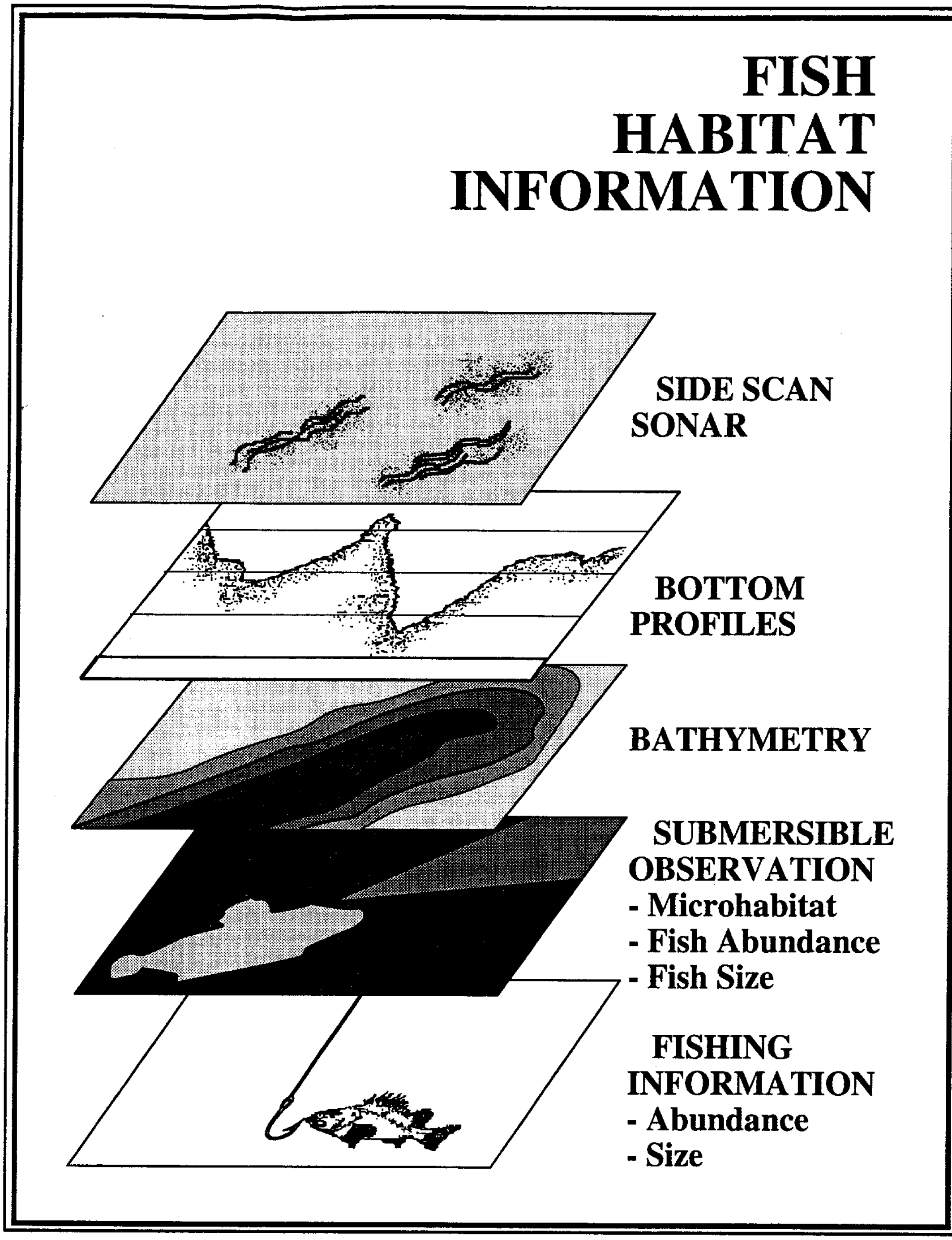

Figure 1. Data sets used to evaluate rockfish assemblages and associated habitat.

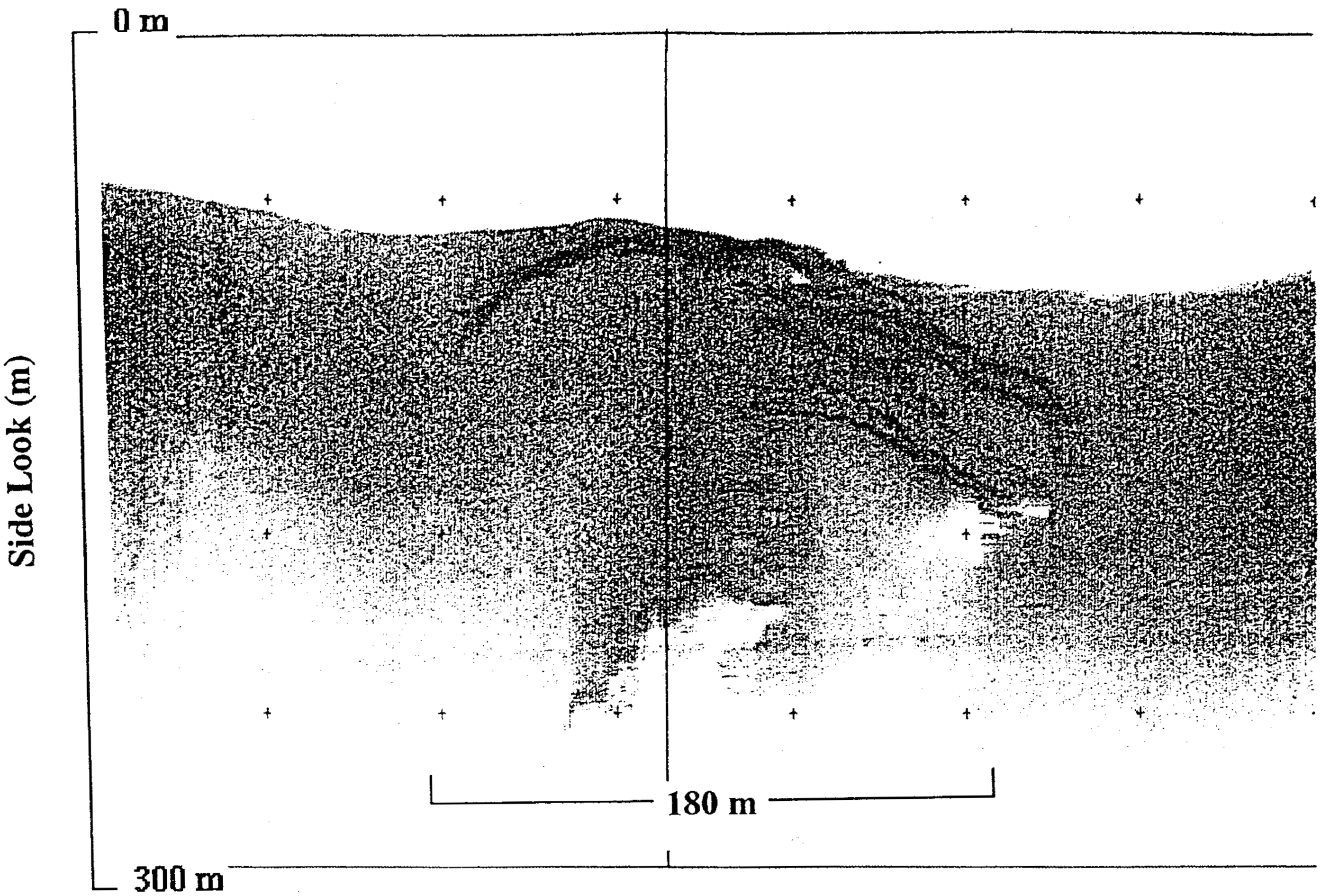

Figure 2. Side-scan sonograph of rock outcrop on steep submarine canyon wall in Monterey Bay. Strong acoustic reflectors are from exposed bedding faces, white areas are shadows behind faces, and gray areas are nonreflective mud. These mudstone beds comprise rockfish habitat. Interpretations were verified by direct observations from submersible.

A GEOPHYSICAL APPROACH TO CLASSIFYING MARINE BENTHIC HABITATS: MONTEREY BAY AS A MODEL

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Introduction

Remote sensing and large-scale mapping of potential habitat for benthic organisms contribute to a more efficient use of manned submersibles and remotely operated vehicles (ROV) during *in situ* seafloor investigations. Because many benthic habitats are defined by their geology (along with depth, chemistry and other attributes), geophysical techniques are critical in determining habitat structure and lithology (rock type). Such geological descriptions then can be applied to associated biological communities.

Until recently, assessment of benthic marine habitats and their biological assemblages largely has been limited to subtidal (<ca. 30 m) *in situ* observations. Increased availability and use of underwater video systems on ROVs, submersibles, and sleds have made fine-scale surveys in deep water more commonplace, thereby expanding our understanding of the processes that help define these communities and the spatial scale at which these processes operate. With the support of the West Coast National Undersea Research Center, a cooperative project between geologists and fishery biologists was recently undertaken in Monterey Bay (Yoklavich et al. 1994). In this paper, we discuss the geophysical procedures used to map seafloor geology, and their potential for describing relatively deep (>50 m), marine benthic habitats for fishes. We propose a classification of benthic habitats that is applicable to the rockfish assemblages being studied in the Monterey Bay area and suggest this classification be developed as a model for characterizing benthic habitats elsewhere.

Marine geophysical methodologies used to investigate benthic habitats of Monterey Bay include side-scan sonar and seismic reflection profiling. These techniques use sound sources of different frequencies to produce images of surface and subsurface features. Reflected sound waves are recorded as seafloor images in plane, areal, and cross-section views. Resultant maps of morphology, textures, and structure can be related to lithology.

Side-Scan Sonar

Side-scan images are created by reflections of sound waves from the seafloor surface. The transceiver (sound source) is towed from a ship at a constant height above the seafloor; height above seafloor is related to desired swath width. Very high frequency ($\sim$ 100 kHz) sound emanates from both sides of the source and sweeps the seafloor with a swath width of up to 1 km. Generally, closely spaced ship track lines assure sufficient overlap to mosaic the images or sonographs.

Two side-scan systems (EG&G Seafloor Mapping System and a Klein System) were used in Monterey Bay, each with a 100 kHz sound source. Each side of the swath varied from 300 to 500 m. In steep terrain, such as along the walls of submarine canyons, only one channel (side) of the "fish" received usable echoes; under these circumstances, close spacing of track lines was necessary to achieve adequate overlap for mosaics. Seafloor morphology is imaged on a sonograph that resembles the negative of a black-and-white photograph (Figure 1). Strong reflection and shadows create an image from which we distinguish features, such as bedrock outcrops, muds, sands, gravel, landslide scarps, and debris, faults, folds, and often general lithologies; i.e., granite, volcanic rock, or bedded sedimentary rock. These images are used to identify likely fish habitats that can be examined more closely with *in situ* equipment.

Seismic Reflection Profiling

Seismic reflections also can be used to map subsurface stratigraphy and structure. We have used this technique to supplement our interpretations of side-scan sonographs. These systems have high resolution (images as small as 0.5 m), shallow penetration (less than 500 m), and generally use a high frequency ($\sim$ 1,000–1,500 Hz) sparker- or transducer-type sound source towed by the survey vessel at the sea surface. A short ($<$ 10 m) hydrophone streamer also is towed behind the vessel ($\sim$ 1 m beneath the sea surface) to receive echoes from subsurface features.

Seismic reflection profiles are time-distance graphs, that when corrected for true velocity of sound through the water column and seafloor, depict a geologic cross section of the stratigraphy along the survey vessel's track. From this we can identify subsurface structures that influence seafloor morphology associated with likely habitats.

Geologic Setting of Monterey Bay

Monterey Bay is a nearly crescentic bay that indents an otherwise straight coastline by about 10 km (Figure 2). The floor of the bay is generally flat, ranging in water depth from 0 m at the shoreline to 100 m near its outer margin. A major submarine canyon system bifurcates the bay producing deep incisions that disrupt the generally flat nature of the seafloor. The Monterey Canyon system is composed of three canyons: Monterey Canyon proper and 2 tributaries and Carmel and Soquel Canyons (Figure 3). Monterey Canyon extends from near the shoreline at Moss Landing and is the primary conduit for transporting sediments from the shelf to abyssal depths. Soquel Canyon cuts the northern Monterey Bay shelf, is far removed from the shoreline, and appears not to be active as far as transporting sediment to

Monterey Canyon. Carmel Canyon is eroded along the Palo Colorado-San Gregorio fault zone that trends northwest-southeast along the western margin of the bay.

Monterey Bay lies in a very active geologic and tectonic setting. It is situated between the seismically active San Andreas and Palo Colorado-San Gregorio fault zones, and its geomorphology is the direct result of tectonic processes along the transform and oblique convergent boundary between the North American-Pacific Plates (Greene 1990). Additionally, the Monterey Bay fault zone trends northwest through the bay from the Monterey bight and merges with the Palo Colorado-San Gregorio fault zone just northwest of Santa Cruz. Movement along faults within the Monterey Bay fault zone is actively deforming the seafloor in Monterey Bay today (Figure 2).

The oblique convergence of the Pacific Plate against the North American Plate, and motion within the San Andreas fault system have created areas of compression and tension (Greene 1990). This fault motion has transported and slivered a granitic basement block (the Salinian Block) into the Monterey Bay region from the block's origin further to the south (Page 1970; Greene 1990). During the transport of the Salinian Block in the past 27 million years, submergence (tension) below and emergence (compression) above sea level resulted in deposition of Tertiary marine sediment and erosion of previously deposited sediment. Additionally, large-scale erosion of the submarine canyon has created a region of extremely diverse and complex geomorphology and lithology.

Due to its dynamic Cenozoic tectonic history, lithologies are represented by igneous intrusions, volcanism, deep- and shallow-water sedimentation, carbonate buildup, and wind-driven deposition. In addition, extremely diverse physiographic provinces exist within Monterey Bay, ranging from flat Continental Shelf, steep Continental Slope and Rise, and steep-walled canyon environments, to shallow seafloor with bedrock banks and knolls (Greene and Hicks 1990; Greene et al. 1993; Orange et al. 1993). The variety in geologic composition makes Monterey Bay an excellent region for characterizing benthic habitats.

Monterey Bay: A Model for Classifying Benthic Marine Habitats

We are in the process of using the Monterey Bay as a model to characterize benthic habitats for commercially and recreationally important species of fishes. These habitats can be categorized on the basis of depth, geology, physiography and geomorphology, slope or inclination, substratum morphology, structure, texture, and associated biotic communities. All habitat categories can be modified by terminology that is applicable across many higher levels of classification. Many habitats can be described as a mosaic of several subcategories. Our main objective is to develop a common framework based on geologic descriptors and processes from which biologists and ecologists can describe, visualize, and interpret functional assemblages of marine benthic organisms and their habitats. A classification system of geologic characteristics of the seafloor specific to biological applications will assist in identifying benthic habitats and is essential in evaluating marine coastal resources. Our habitat classification scheme is modified from those developed for shallow-water estuarine and marine systems (Cowardin et al. 1979; Dethier 1992).

System (based on salinity; proximity to seafloor):
- *Marine Benthic*

  Subsystem (based on physiography; depth):
  - ***Shelf***
    - *Intertidal (salt spray to extreme low water)*
    - *Subtidal (0–30 m)*
    - *Intermediate (30–100 m [location of shelf break])*
  - ***Slope***
    - *Upper (100 m [location of shelf break]–500 m)*
    - *Intermediate (500–1,000 m)*
    - *Lower (1,000+ m)*
  - ***Submarine Canyons***
    - *Head (10–100 m)*
    - *Upper (100–300 m)*
    - *Middle (300–500 m)*
    - *Lower (500–1,000+ m)*

    Class (based on bottom morphology):
    - *Bars*
    - *Sediment waves*
    - *Banks*
    - *Caves, crevices (ragged features)*
    - *Sinks*
    - *Debris field, slump, block glide, rockfalls*
    - *Grooves, channels (smooth features)*
    - *Ledges*
    - *Vertical wall*
    - *Pinnacles*
    - *Mounds, buildups, crusts (>3 m in size)*
    - *Slabs*
    - *Reefs (carbonate features)*
      - *biogenic*
      - *nonbiogenic*
    - *Scarps, scars*
    - *Terraces*
    - *Vents*
    - *Artificial structures (wrecks, breakwaters, piers)*

      SubClass (based on substratum textures):
      - *Organic debris (coquina, shell hash, drift algae)*
      - *Mud (clay to silt; <0.06 mm)*
      - *Sand (0.06–2 mm)*
      - *Gravel*
      - *Pebble (2–64 mm)*

<u>SubClass</u> (based on substratum textures [continued]):

Cobble (64–256 mm)
Boulder (0.25–3.0 m)
Bedrock
  Igneous (granitic, volcanic)
  Metamorphic
  Sedimentary

<u>SubClass</u> (based on slope):

Flat (0–5°)
Sloping (5–30°)
Steeply sloping (30–45°)
Vertical (45–90°)
Overhang (>90°)

<u>Modifiers</u>

- for bottom morphology

regular
irregular (continuous, non-uniform bottom with local relief 1–10 m)
hummocky (uniform bottom w/ mounds/depressions 0–3 m)
structure (fractured, faulted, folded)
friable
outcrop (amount of exposure)
bedding
massive

- for bottom deposition

consolidation (unconsolidated, semi-consolidated, well-consolidated)
erodability (uniform, differential)
sediment cover
  dusting (<1 cm)
  thin (1-5 cm)
  thick (>5 cm)

- for bottom texture

voids (percentage volume occupied by clasts or rock)
sorting
packing
density
  occasional (random occurrence of feature; e.g., boulder)
  scattered (feature covers 10–50% of area)
  contiguous (features are close to touching)
  pavement (features are touching everywhere)
lithification
jointing
clast (rock) roundness
clast shape

Modifiers

- ***for bottom texture*** *(continued)*
    - *blocky*
    - *lensoidal*
    - *boitroidal (e.g., pillow lava)*
    - *needle-like*
    - *angular*

- ***for physical processes***
    - *currents*
        - *winnowing*
        - *scouring or lag deposits*
        - *sediment trail*
    - *wave activity*
    - *upwelling*
    - *seismic*

- ***for chemical processes***
    - *vent chemistry (sulfur, methane, freshwater,* CO_2*)*
    - *cementation*
    - *weathering or oxidation (fresh to highly weathered)*

- ***for biological processes***
    - *bioturbation (tracks, trails, burrows, excavation)*
    - *cover of encrusting organisms*
        - *continuous (> 70%)*
        - *patchy (20–70% cover)*
        - *little to no cover (< 20%)*
    - *communities (examples of conspicuous species)*
        - <u>*Metridium sp*</u>.
        - *crinoids*
        - *vase sponges*
        - *coraline algae*
        - *kelp understory*
        - *sea grasses*
        - *kelp forest*

Examples of Marine Benthic Habitats in Monterey Bay

While a variety of benthic habitats exist in Monterey Bay, we will only describe 2 of these in this paper. Soquel Canyon and Portuguese Ledge represent 2 end members consisting of a deep (~300 m) habitat with steep relief and a shallow (~100 m) habitat of low relief or generally flat (Yoklavich et al. 1992; Greene and Sullivan 1993; Greene et al. 1994; Yoklavich et al. this publication).

Soquel Canyon

Soquel Canyon is a dormant, submarine canyon that appears to not be actively eroding today (Figure 3). The last erosion event was during the Pleistocene, when sea level was lower and the San Lorenzo River drained from the southern Santa Cruz Mountains onto the exposed northern bay floor. At this time, undercutting of the walls of the canyon caused extensive landslides; one near the mouth of the canyon blocked the canyon axis and caused ponding of sediment upcanyon. Our area of interest is in the headward part of the canyon, between 100 and 300 m. Here, the canyon cuts the generally flat-lying beds of the Pliocene Purisima Formation, a shallow-water marine deposit consisting of interlayered sandstone, mudstone, and shell hash (coquina).

Side-Scan Sonar. Side-scan sonographs collected along the headward part of Soquel Canyon show an area of steep relief with morphology varying from gentle slopes (~30°) to near-vertical cliffs. Arcuate slump scarps were imaged along the upper walls of the canyon, and extensive slump-debris fields composed of large (meters in dimensions) angular to subrounded blocks to small boulders were found concentrated at the base of the walls and out into the canyon axis (Figure 1). Most of the canyon was so steep that only one channel (side) could be used to receive reflected signals. Using a 600-m swath width (300 m per channel), a mosaic was constructed that imaged the slump features and outcrops of well-layered sedimentary rocks.

Seismic Reflection Profiles. Seismic reflection profiles show the subsurface structure of the canyon to be locally faulted and to have a fairly thick (< 100 m), flat-lying, well-layered sedimentary section. Well- defined reflectors continue beneath the canyon axis, indicating the canyon is located completely within the Purisima Formation. However, shoreward of the head, beneath the shallow (> 100 m) seafloor, folds, faults, and apparent gas-charged zones suggest that Soquel Canyon may be structurally controlled, and erosion may have been precipitated through fluid flow and gas venting (Figure 4).

Submersible Dives. DSV *Delta* submersible dives confirmed the existence of slump scarps, landslide debris, and exposures of well-layered, friable, differentially eroded sedimentary rocks. Rocky outcrops of differentially eroded beds provide overhangs and caves that attract rockfishes (Figure 5). Boulder landslide debris also provide suitable habitat for rockfishes. More gently inclined (20–30°) slopes, covered with mud and organic detritus, occur in between slump scarps and bedrock exposures. Blocky landslide debris composed of scattered boulders interspersed with highly bioturbated muds occur at the base of the canyon walls and in the axis of the canyon.

Habitat Characterization. Based on the habitat characterization scheme above and interpretation of the geophysical data collected in Soquel Canyon, along with submersible observations, we characterize this habitat as follows:

> Upper submarine canyon (100-300 m), steeply sloping (30-45°) walls, locally including vertical walls (80–90°), with landslide (slump scarps and debris field) morphology and well-bedded, friable, differentially eroded outcrops of sandstone, mudstone, and coquina. Differentially eroded beds along the canyon walls form overhangs (> 90°) and crevices. Landslide debris produces irregular seafloor conditions consisting of scattered, blocky boulders of sandstone interspersed with a fairly bioturbated mud seafloor.

Lithology, geomorphology, depth range, and other physical conditions in Soquel Canyon provide suitable habitat for many species of rockfishes. Further analyses of the geophysical, geological, and biological data will provide specific associations of rockfish assemblages and their microhabitat.

Portuguese Ledge

Portuguese Ledge is a basement and bedrock outcrop that rises several meters above the flat, sandy seafloor of the southern Monterey Bay shelf (Figure 3). The shelf is a wave-planed surface that represents the latest sea-level rise and advancement to the present day shoreline. Due to the resistant nature of Portuguese Ledge rocks (granite and shales) and movement along the Monterey Bay fault zone that resulted in uplift (through compression), the rocky bank remains exposed today and exhibits a faulted, flat-topped to gently irregular surface. This bank lies in water depths of ~ 100 m and is composed of Cretaceous granitic basement rocks of the Salinian block and diatomaceous mudstones (shales) and radiolaria chert of the Miocene Monterey Formation.

Side-Scan Sonar. Due to the relatively subtle relief of Portuguese Ledge when compared to Soquel Canyon, a 1-km (500 m/channel) side-scan sonar swath width with 100% overlap resulted in a fairly complete mosaic of the bank. From the sonographs, rectangular basement and bedrock outcrop appear to be bounded in many places by linear scarps, possibly formed from both faulting and erosion (Figure 6). These scarps generally rise ~ 1 m above the surrounding flat, sandy seafloor. The surface of the bank varies from repetitively bedded, gently to steeply dipping shales to massive granitic rocks textured with crosscutting joint sets. The surface of the bank is generally flat, but locally the surface can be defined as gently irregular.

Seismic Reflection Profiles. Seismic reflection profiles collected across Portuguese Ledge exhibited gently to steeply dipping sedimentary rocks and faulted basement. From the seismic reflection profiles, many of the steep scarps identified in the sonographs appear to be controlled by faults. Seismic reflection profiles collected adjacent to the bank show faulted sedimentary rocks that have been deformed from movement within the Monterey Bay fault zone.

Submersible Dives. Observations from the DSV *Delta* submersible confirmed that Portuguese Ledge is composed of granitic basement rocks and shales of the Monterey Formation. The rocky outcrops of meter-high granitic scarps and exposed folded and faulted sedimentary rocks form habitats suitable to diverse rockfishes.

Habitat Characterization. Using the habitat characterization scheme above, as well as geophysical interpretations and submersible observations, we define the Portuguese Ledge habitats as follows:

> Intermediate shelf (30–100 m) with a massive granite and bedded shale bank, lightly grooved with a flat to gently irregular surface. Some margins of the bank are faulted and form meter-high scarps. The granite surface is fractured from crosscutting joint sets. The bank is surrounded by sands and gravel that have been deposited in a strong current regime.

Conclusions

Geophysical techniques that define large-scale, marine benthic features are extremely valuable in selecting and targeting habitats for further submersible and ROV observations. Interpretations of side-scan sonar and seismic reflection data were used to locate dive sites in Soquel Canyon and Portuguese Ledge areas of Monterey Bay. Submersible observations confirmed the habitat characterization as initially described by geophysical interpretations. We suspect that similar habitats exist elsewhere and that characterization studies underway in Monterey Bay can be used as models for describing habitats outside the Monterey Bay region.

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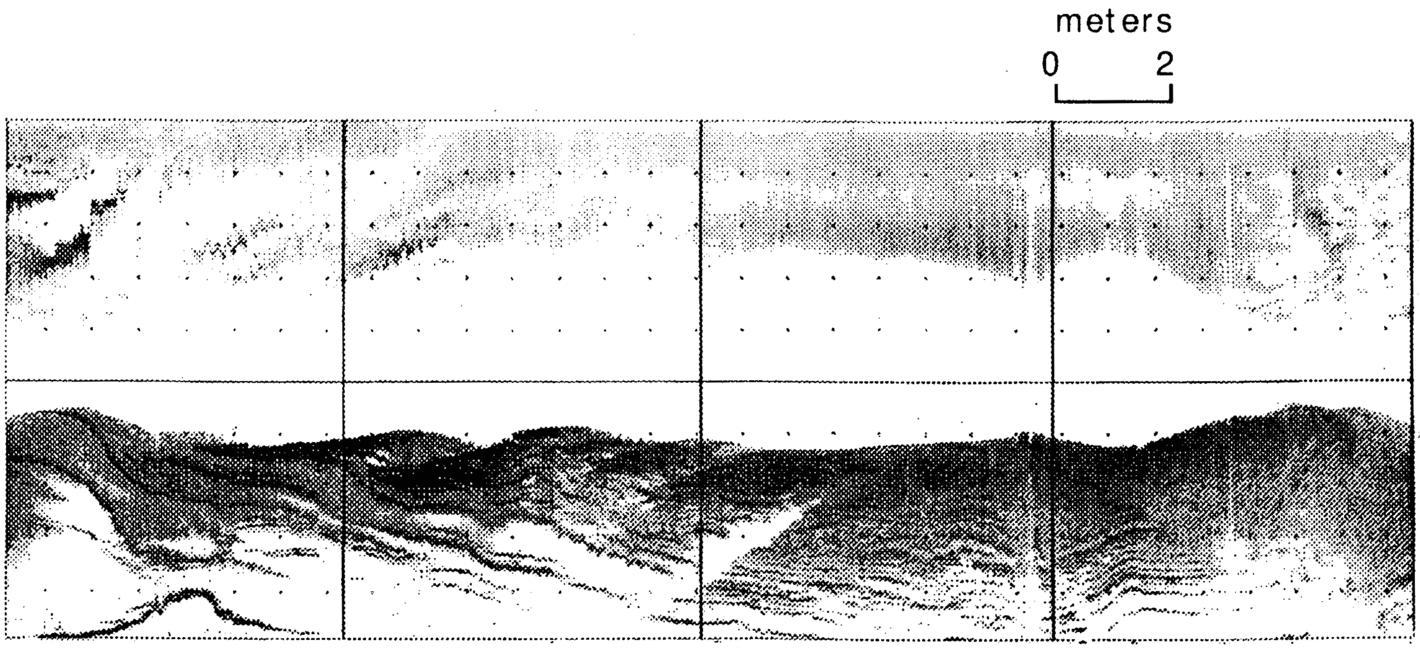

Figure 1. Side-scan sonograph showing imaged seafloor morphology along the eastern wall of Soquel Canyon.

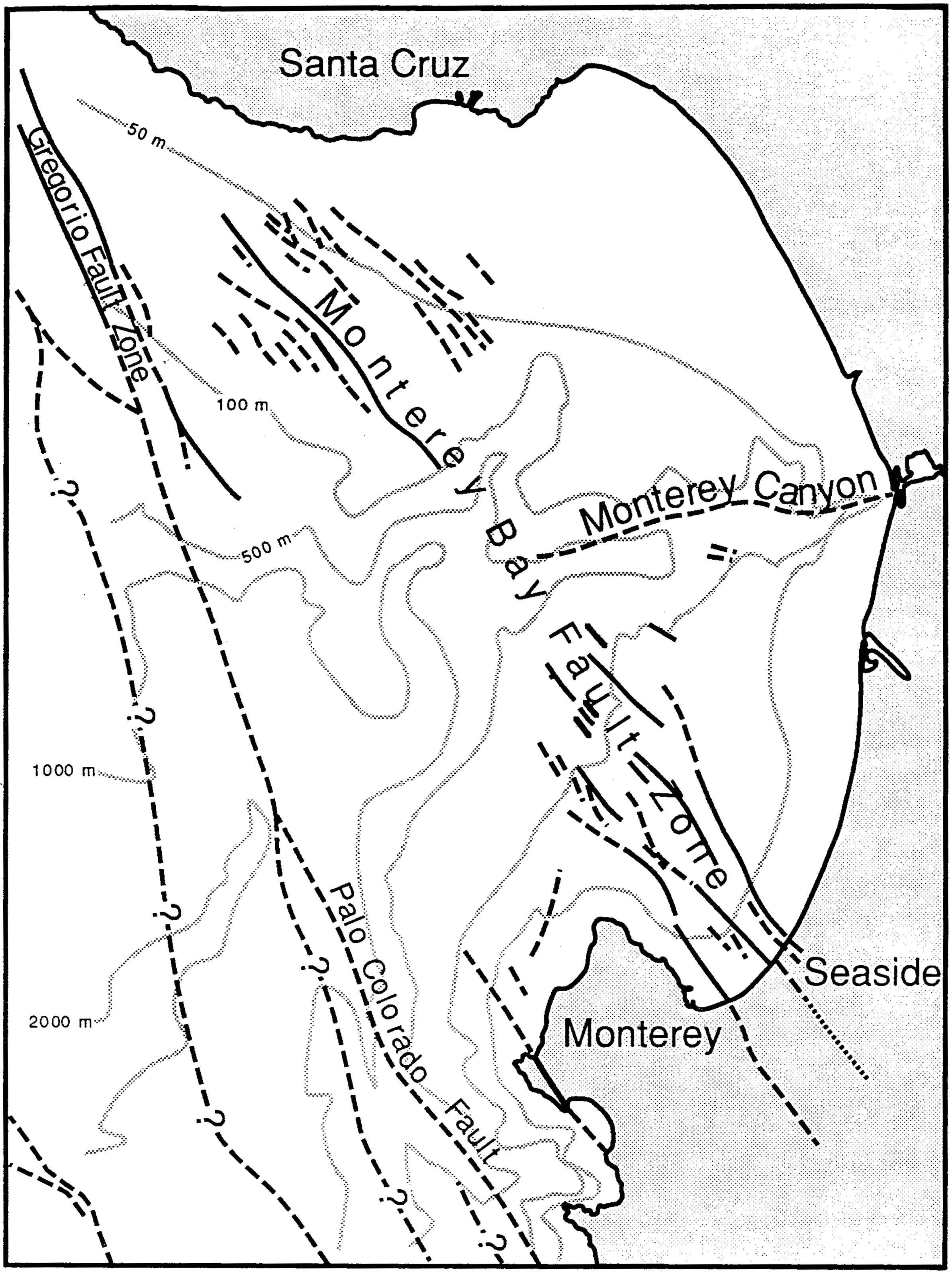

Figure 2. Faults and major physiographic features of the Monterey Bay region.

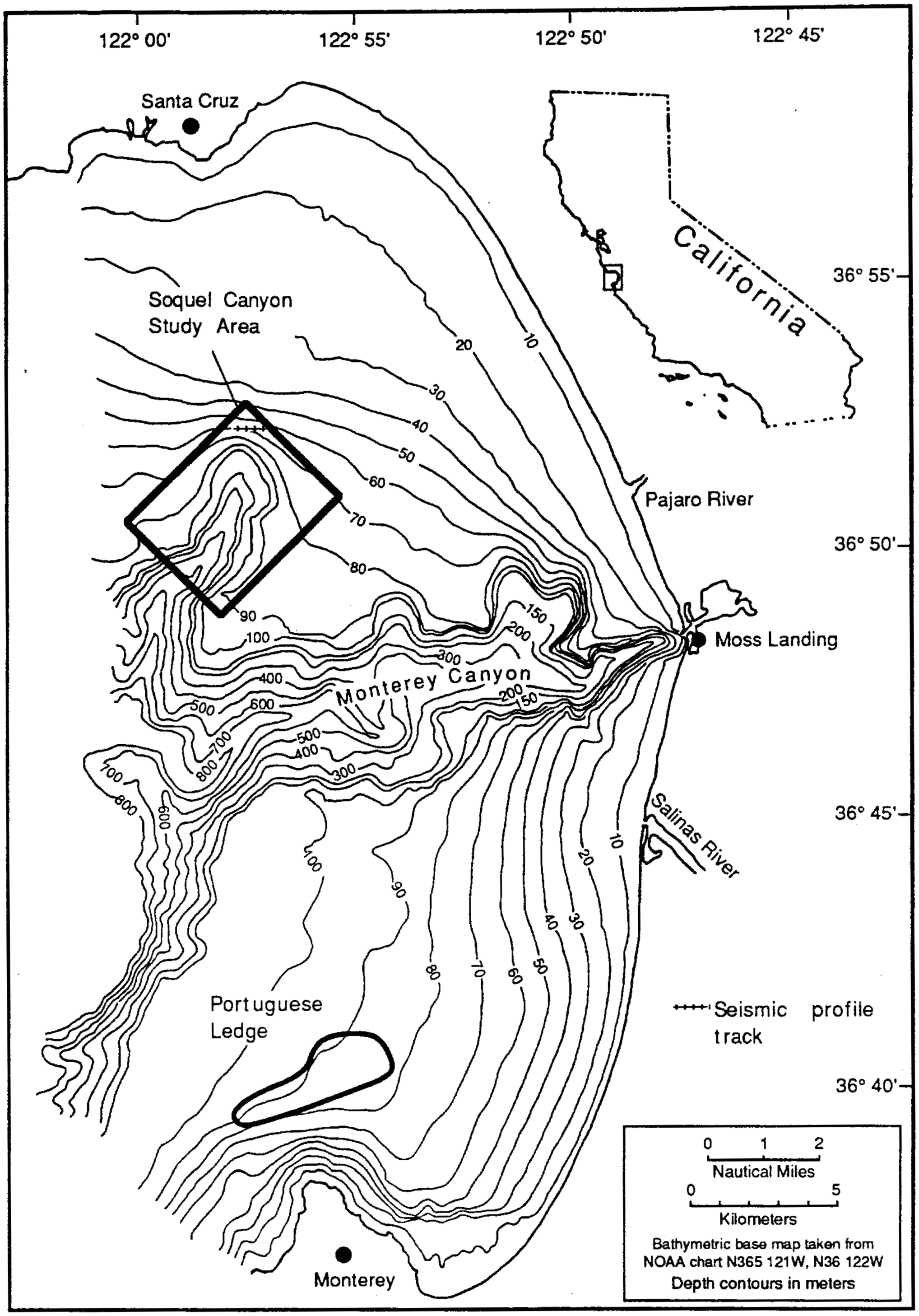

Figure 3. Locations of the Soquel Canyon and Portuguese Ledge marine benthic habitats of the Monterey Bay area.

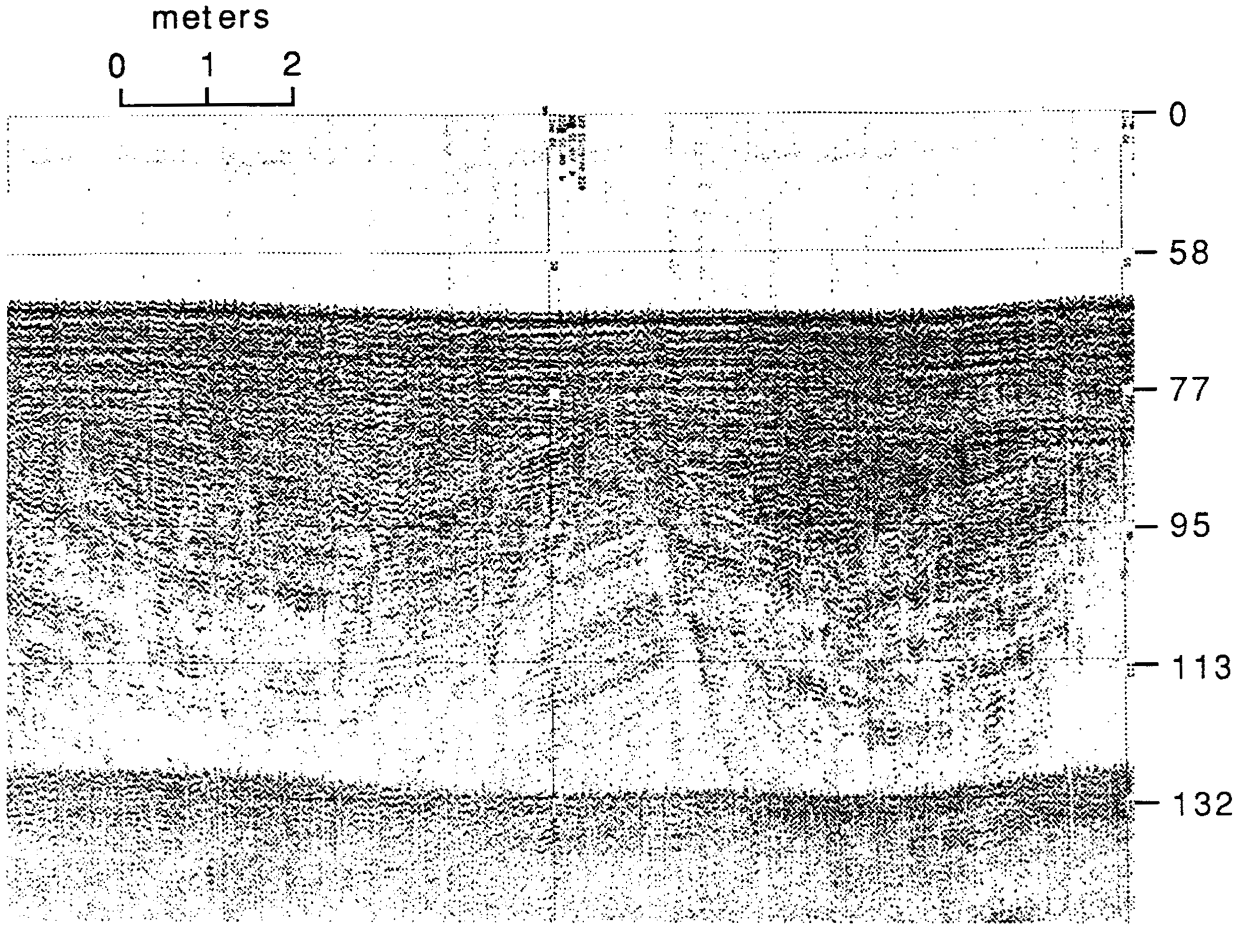

Figure 4. Seismic-reflection profile across headward part of Soquel Canyon, showing folds, faults and gas-charged sediments (see Figure 3 for location).

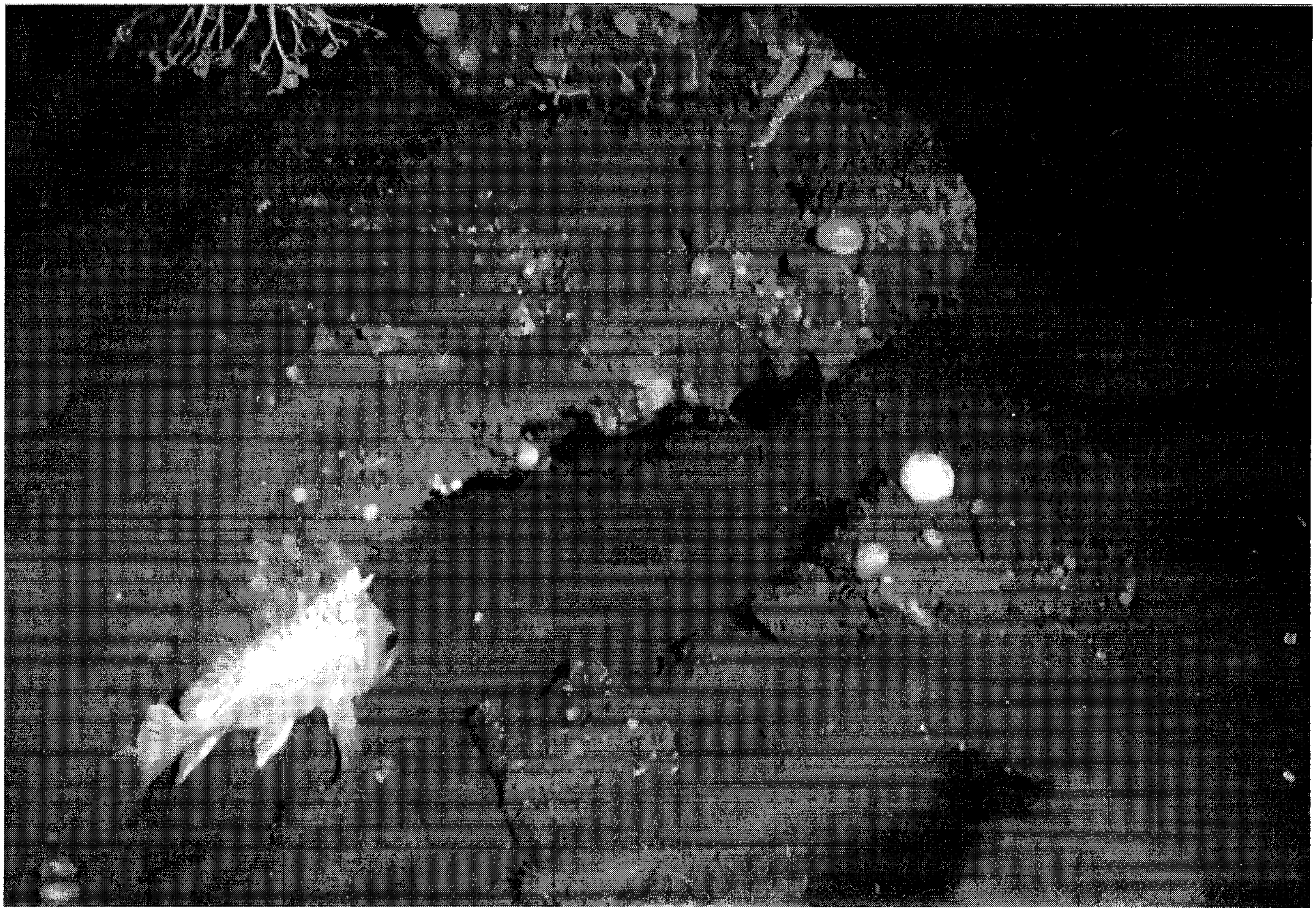

Figure 5. Photo taken from DSV *Delta* submersible showing differentially eroded beds of the Purisima Formation in Soquel Canyon and adult greenspotted rockfish (*Sebastes chlorostictus*).

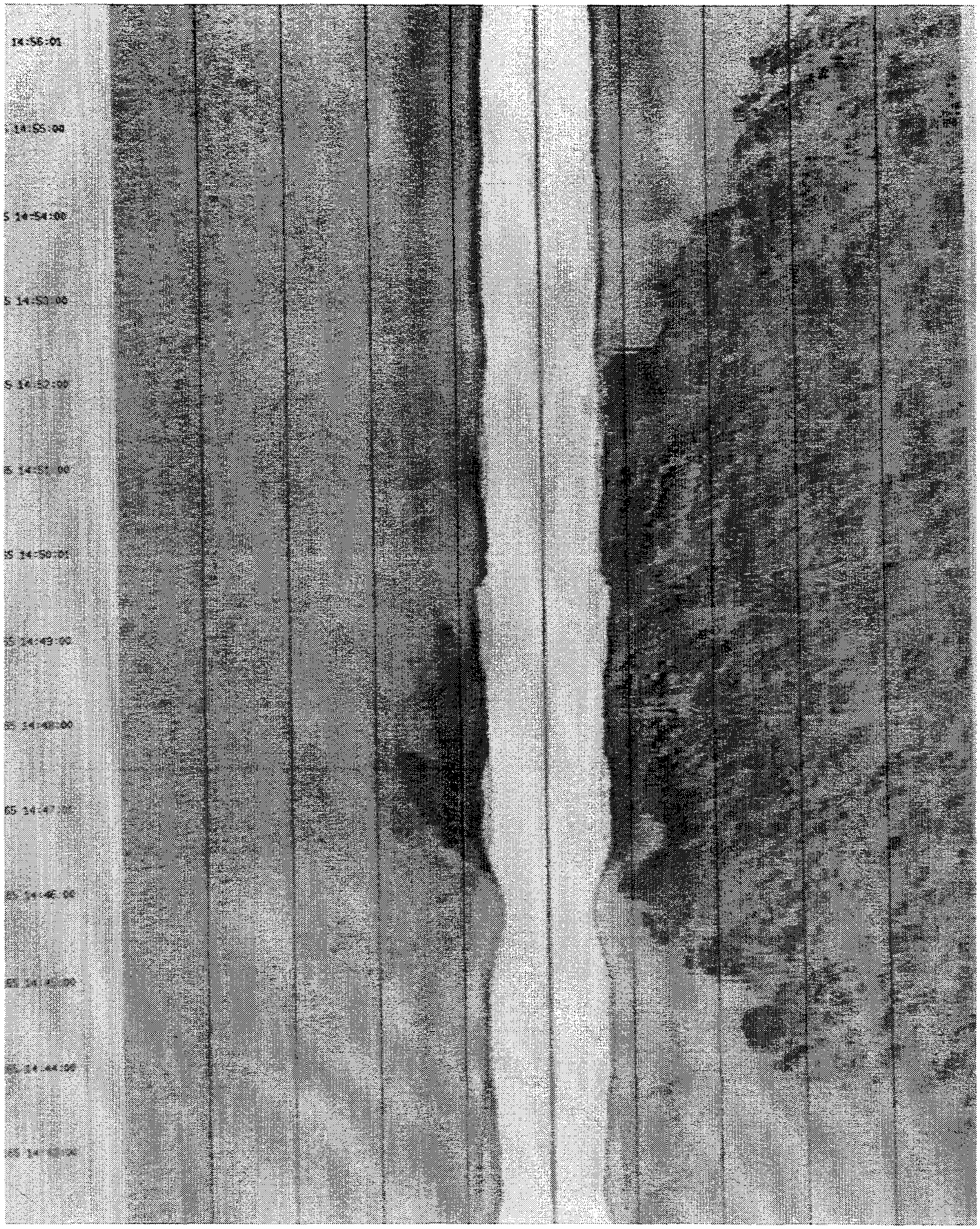

Figure 6. Side-scan sonograph across Portuguese Ledge showing cracks and crevices in granitic rocks.

GEOLOGICAL MAPPING OF BIOLOGICAL HABITATS ON GEORGES BANK AND STELLWAGEN BANK, GULF OF MAINE REGION

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Introduction

Biological habitats play a vital role in the life cycles of commercial and recreational fisheries species and in the maintenance of ecological diversity. Habitat substrate is of particular importance to the reproduction and survival of benthic organisms and other species that spend a part of their life cycle in, on, or near the seabed. Sediment texture and consistency, bottom morphology, strength of bottom currents, and erosion, transport, and deposition of sediments are major attributes of habitats.

At present, biological habitats in many of the nation's coastal and offshore regions are being impacted adversely by human activities, which include overfishing, physical disturbance of the seabed by fishing gear, and pollution by contaminants introduced in runoff and disposed wastes. Storms, a natural hazard, are the most important forces altering the seabed in some regions.

Recent seafloor mapping studies on Georges Bank and Stellwagen Bank (Figures 1-3) suggest that sedimentary environments and processes play a major role in the success of species (Lough et al. 1989, 1992; Valentine 1991; Valentine and Lough 1991, 1992; Valentine and Schmuck 1993; Valentine et al. 1992, 1993). These studies have been conducted by the U.S. Geological Survey (USGS) in cooperation with agencies of the National Oceanic and Atmospheric Administration ([NOAA] National Marine Fisheries Service, Sanctuaries and Reserves Division, and National Undersea Research Program).

Habitat mapping is an emerging research topic. A knowledge of the distribution and dynamics of biological habitats and the amount of degradation that has occurred within them is essential for scientists and policymakers who are planning research and monitoring strategies for the purpose of preserving and managing the nation's environmental and fisheries resources. This knowledge can be gained by collaborative research involving geologists and biologists to produce maps and other data which characterize and document the geographic extent of important biological habitats, the geological processes which form and alter them, and the rates at which changes in habitats occur.

Mapping Objectives and Techniques

The objectives of habitat mapping are to characterize the seabed in terms of texture and morphology, sediment movement, effects of physical disturbance by storms, trawling and dredging, distribution of benthic species, and dependence of species on particular habitats for survival.

Study of habitats requires the use of geological techniques in conjunction with biological sampling. Side-scan sonar imagery shows the distribution of sediment types, bedforms, bottom roughness, and seabed disturbance caused by fishing gear and tidal and storm currents. Mud, rippled sand, gravel patches, boulders, and dredge and trawl marks are easily distinguished using a side-scan sonar system which operates at a frequency of 100 kHz and images a 200-m-wide swath along the ship's track. Detailed mapping requires a full-coverage, side-scan sonar survey and the collection of many sediment samples, coupled with video observations. High-resolution seismic profiling and echo-sounding surveys provide information on the height and distribution of sand waves and rock outcrops, the thickness of surficial sediments, and the relative hardness and slope of the seafloor.

Visual observations of the seabed using video-equipped samplers, ROVs, and submersibles are essential for interpreting side-scan sonar and seismic data and for documenting substrates and species assemblages in various habitats. Mapping studies based on blind bottom grab samples or cores could misinterpret habitats. Such samples do not reveal the presence of current ripples on the seafloor, textural and biological patchiness, or that, for example, the environment responsible for creating a gravel pavement that caps sandy sediment is misrepresented by a grab sample of mixed sand and gravel.

Georges Bank

Environmental Setting

Georges Bank is a shallow (3–150 m water depth), elongate extension of the northeastern U.S. Atlantic continental shelf east of New England (Figure 1). It covers an area of approximately 40,000 km^2 and is bounded on the north by the deeper waters of the Gulf of Maine and on the south by the Atlantic Ocean. The bank is eroding, and no sediment is transported to it from the continent or from adjacent shelf regions. Glacial debris covers the bank, and sand is winnowed from it and transported into deep water by storm currents and by strong semidiurnal tidal currents that reach maximum speeds of 100 cm/s on the seabed.

The seafloor sediment on eastern Georges Bank is a key element in the development of biological habitats (Figure 2). Since the retreat of glaciers, the bank's surficial sediment has been reworked by the actions of a rising sea and by tidal and storm currents. As a result, sediment texture varies greatly on the bank, ranging from very coarse gravel to sand. In sandy, shallow areas (3–50 m water depth), strong tidal and storm currents have constructed large dunes and sand ridges. These currents also have transported sand into deep water, leaving the gravel behind. A thin gravel pavement has formed on the northeastern part of the bank; this pavement includes several areas of rough seafloor where many boulders are present and constitute fishing hazards. The gravel pavement is a newly discovered seabed feature that extends for 150 km along the northern edge, covering an area of more than 3,000 km^2. In deeper areas of the bank, bottom currents and sediment movement are slower, and the seabed is smoother and finer-grained.

Results of Mapping Studies

Studies conducted on eastern Georges Bank by the USGS and NOAA agencies have revealed important relationships between fishery species and the sedimentary environment (Lough et al. 1989; Valentine and

Lough 1991). Distribution patterns of juvenile cod on eastern Georges Bank show that pelagic juveniles are present in the water column over the entire area in June; by early July, the juveniles have descended to the seabed and are widely dispersed over the same area. However, in late July and August, demersal juveniles are present only in the gravel habitat. These observations, made over several years, suggest that the gravel seabed is the habitat where juvenile cod are best able to avoid predators and to find food sources. Therefore, the gravel is essential for their survival and recruitment to the fishery.

Sea scallops on eastern Georges Bank are most abundant on gravel or sand habitat, and they are almost absent in shallow, sandy areas that are affected by strong tidal and storm currents and have mobile sand waves and ripples. The scallop distribution appears to be related to an inability of juveniles to colonize areas of the bank, where strong currents and shifting sand might bury them or clog their feeding apparatus.

The historical herring spawning grounds on eastern Georges Bank are located where the strongest tidal currents flow over the gravel pavement, producing a unique environment where the eggs can become attached to a firm substrate and hatch in clean, oxygenated water. This habitat is limited to the shallow, western part of the gravel seabed between 67° 10' W and 67° 35' W longitude on the bank's northern edge.

Physical disturbance of the seabed is caused by strong, erosive tidal and storm currents, which construct and move sandbed forms across the bottom. The moving sand alternately buries and exposes other seafloor habitats and thereby alters the structure and composition of the biological community. In addition to this natural reworking of the surficial sediments, much of eastern Georges Bank is disturbed by trawling and dredging for groundfish and scallops. In gravelly areas of the northern edge, where boulders are common and fishing activity is low, there exists a biologically diverse community dominated by abundant attached organisms. The presence of these organisms increases fine-scale biological roughness, and this modification of the seabed may be an important aspect of the fisheries habitat. By contrast, in heavily trawled areas of the gravel seabed, the attached species are poorly represented, and the bottom is relatively smoother.

Stellwagen Bank

Environmental Setting

Stellwagen Bank is a sandy and gravelly topographic high of glacial origin that lies in the Gulf of Maine off the Massachusetts coast north of Cape Cod (Figure 3). It is approximately 15 km wide and 40 km long and trends northwest-southeast. Bounded by Stellwagen Basin to the west and the Gulf of Maine to the east, it rises from a depth of 90 m to less than 20 m below sea level. Like Georges Bank, it is isolated from sediment sources and is eroding. In contrast to the northern edge of Georges Bank, tidal currents on Stellwagen Bank are weak, reaching maximum speeds of only 20-30 cm/s. However, Stellwagen Bank lies in the path of strong, northeasterly storms. Wave currents generated by storms in deep water of the Gulf of Maine modify the seabed as they pass over this shallow, sill-like feature.

Results of Mapping Studies

The USGS and NOAA agencies began a side-scan sonar mapping survey of Stellwagen Bank in 1993 (Valentine and Schmuck 1993). Initial results show that the bank's seabed is not a homogeneous sand sheet, as suggested by previous generalized maps of the region (Schlee et al. 1973). It is covered by large expanses of sand, gravelly sand, and shell deposits on its crest and upper flanks, and by boulder fields and mud on its lower flanks. These bottom types provide a variety of habitats for groundfish, scallops, lobsters, sand lance (a food source for some marine mammals), and other species.

Storm winds from the northeast generate currents that play a major role in determining the texture and morphology of the bank surface. Sediment movement principally is storm driven, and the predominant direction of transport is east to west from source areas on the bank's crest and eastern flank. Storm currents erode the bank and disturb the seabed in water depths between 20 and 55 m. Storm features (Figure 4) include fine-grained sand sheets, fields of coarse sand ripples (wavelengths of 30–60 cm) with gravelly troughs that are aligned northwest-southeast on the bank crest, and similarly alined low sand waves that extend down the western flank to a depth of 55 m and have wavelengths of 15–35 m and wide troughs filled with shell debris. These trough deposits are linear and disconnected, but cover 10–20% of the seafloor in the sand-wave areas. Trough deposits comprise densely packed bivalve shells that form a hard-bottom habitat with appreciable biological roughness in an otherwise sandy area.

A resurvey in September 1993 of storm features that were first imaged in April 1993 (and thought to have been formed in December 1992 by a major storm from the northeast) shows no changes in their shape or location during the 5-month period. This observation is evidence that tidal currents are not effective in transporting sand on the bank, and that the origin of the features is storm-related.

In addition to the catastrophic impact of storms on the bank, the side-scan images show that intensive scallop dredging and groundfish trawling reworks large areas of the seabed by destroying surface features and mixing the sediment (Figure 4). The impact of this activity on sandy and muddy habitats is not yet known, but, as described for Georges Bank, dredging in gravel pavement removes attached organisms and prevents their recolonization, thus altering the community structure and habitat.

The data from Stellwagen Bank show that the bank is affected principally by wave-induced currents generated during major storms from the Gulf of Maine and by the trawling and dredging of fishermen. By contrast, the seabed is unaffected by daily tidal currents. Storm-wave currents destroy old habitats and generate new ones, possibly influencing the survival and distribution of bottom-dwelling species. A major storm, or a series of storms within a short period, might adversely affect the recruitment of juvenile fish and bivalves to the fishery.

Practical Applications of Habitat Mapping Results

Georges Bank, once the premier fishing ground on the East Coast, has been overfished to the point that populations of the most desirable species (cod, haddock, flounder, herring, and scallops, among others) have been depleted. The National Marine Fisheries Service estimates that non-commercial dogfish and skate now comprise 75% by weight of all groundfish on the bank (NOAA 1993). The waters and seabed of Stellwagen Bank support commercial and recreational fisheries (groundfish, scallop, tuna), and serve as habitat for marine mammals, including endangered species of whales.

Although Georges Bank and Stellwagen Bank have been fished intensively for many years, the effort to gather information on the distribution of biological habitats and their role in the life cycles of fisheries species is in its initial stages. We present here several possible practical applications of the knowledge gained so far from the studies described above.

Juvenile cod survive best on gravel habitat and are seasonally concentrated in a relatively small region of Georges Bank. These juveniles also exhibit diel behavior; by day they reside on the bottom, oriented into strong semidiurnal tidal currents, whereas by night they rise several meters off the bottom. Thus, (1) the population size of juvenile cod could be assessed by intensive, seasonal sampling of only the gravel habitat instead of the entire bank; (2) juveniles could be protected from trawling and dredging while they are concentrated on the gravel; and (3) sampling strategies for stock assessment could be improved by accounting for the juveniles' diel behavior and orientation into bottom currents.

Sea scallops are most abundant in sand and gravel habitats of eastern Georges Bank that experience little sand movement. Recently settled scallops may be buried or damaged by mobile sand that is transported by tidal currents and storms and by disturbance of the seabed by trawling and dredging. Thus, (1) the population size of scallops could be assessed most efficiently by sampling only habitats where sand movement by tidal currents is not common; (2) the effects of large storms could be evaluated to determine whether they have a long-term impact on scallop populations; and (3) maintenance of the sea scallop stock might be improved by restricting harvesting in some areas of most favorable habitat.

Herring on eastern Georges Bank lay their eggs in relatively small areas of gravel substrate where tidal current flow is strong. The time of spawning is well known, as are the locations of historic spawning sites which are, at present, heavily dredged and trawled for scallops and groundfish. Thus, (1) the areal extent and volume of herring egg beds could be assessed using video, bottom sampling, and possibly side-scan sonar; and (2) damage to the egg beds could be minimized by restricting trawling and dredging during the relatively short period of several weeks in the fall when spawning occurs.

Physical disturbance of the seabed is caused by both human and natural processes. Dredging and trawling in the gravel habitat mixes the seabed sediment, damages attached species, and reduces local diversity, abundance, and biogenic bottom roughness. Storm erosion or deposition of sand alters habitats and thereby effects the distribution of benthic species. Thus, the impact of seabed disturbance on the fishery could be evaluated by determining, for example (1) the effects of reduced biodiversity on the availability of prey species; (2) the effects of reduced biogenic roughness on the survival of juvenile fish; (3) the effects of seabed mixing on availability of nutrients sequestered in sediments; (4) the frequency of disturbance by fishing gear; (5) the rate of reëstablishment of disturbed habitat; (6) the extent of loss or alteration of habitat through sand movement; and (7) the direct effects of storms on benthic species.

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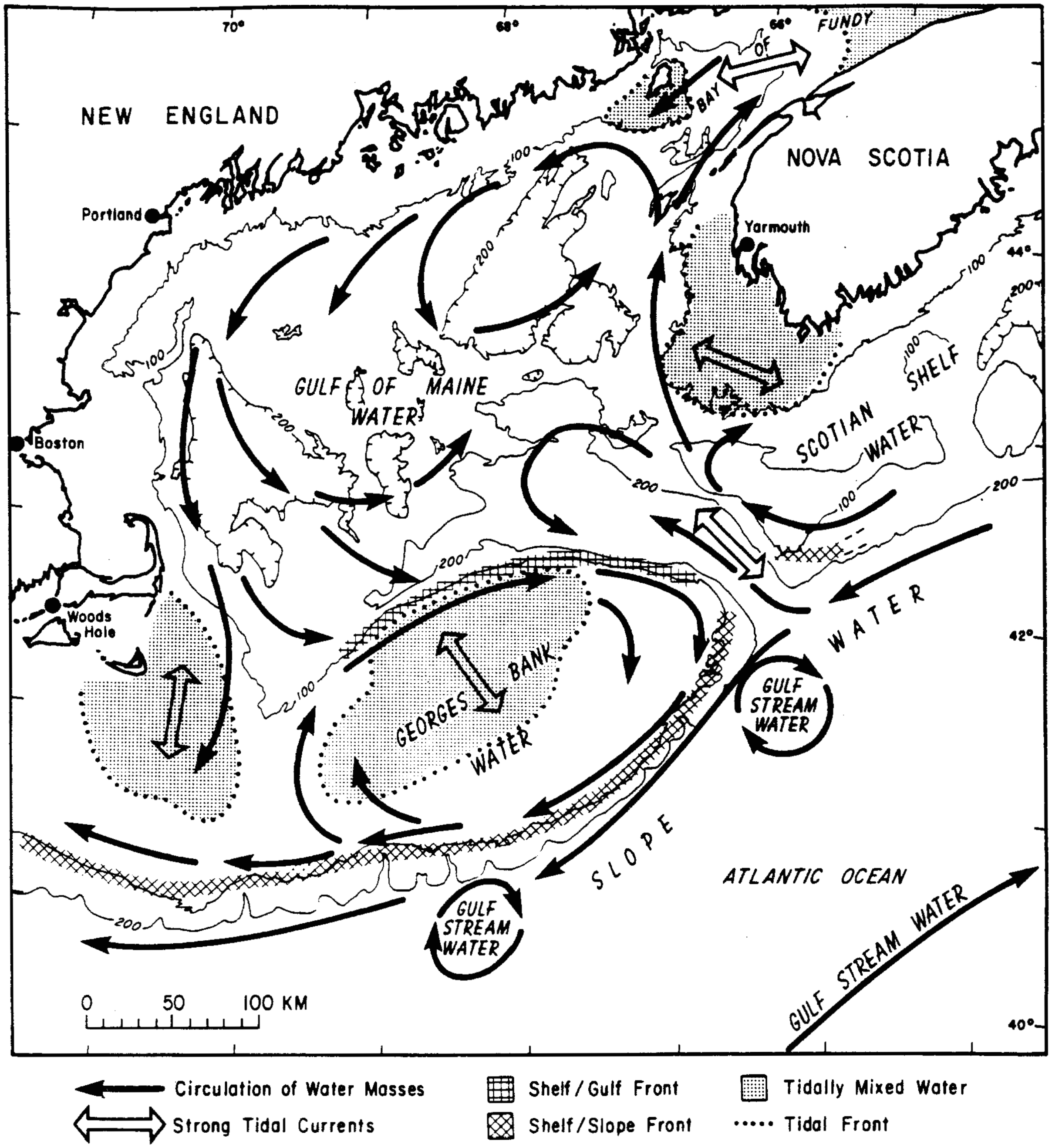

Figure 1. Map showing water-mass circulation patterns in the Georges Bank-Gulf of Maine region. Mixing of bottom and surface waters in shallow areas by strong tidal currents recycles nutrients and leads to high biological productivity. Mapping studies are being conducted on eastern Georges Bank (Figure 2) and on Stellwagen Bank (Figure 3), which are located 60 km east of Boston.

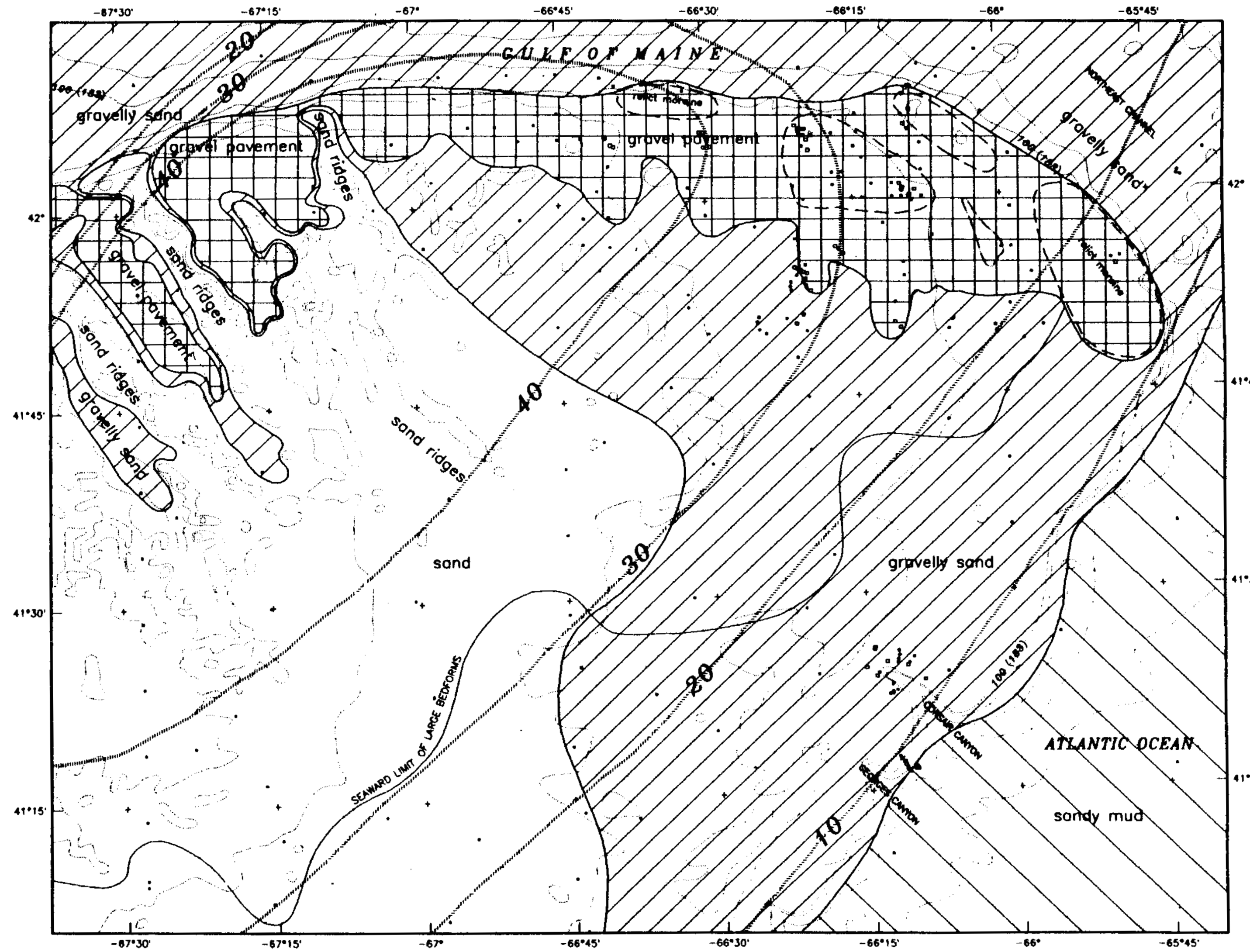

Figure 2. Map showing the sedimentary environment of eastern Georges Bank, including seafloor morphology and texture. Bold, broken lines represent isolines of mean, semidiurnal tidal bottom current speed in cm/s (50 cm/s = 1 nm/hr). The strongest semidiurnal tidal currents flow parallel to sand ridges and reach maximum speeds of 100 cm/s. Bottom sample stations shown. Relict moraines are interpreted to be bouldery regions of gravel habitat deposited by former glaciers; these areas support a more diverse epibenthic fauna and are less frequently dredged and trawled than other parts of the gravel habitat lying to the west. Depths are in fathoms (meters).

STELLWAGEN BANK MAP SERIES

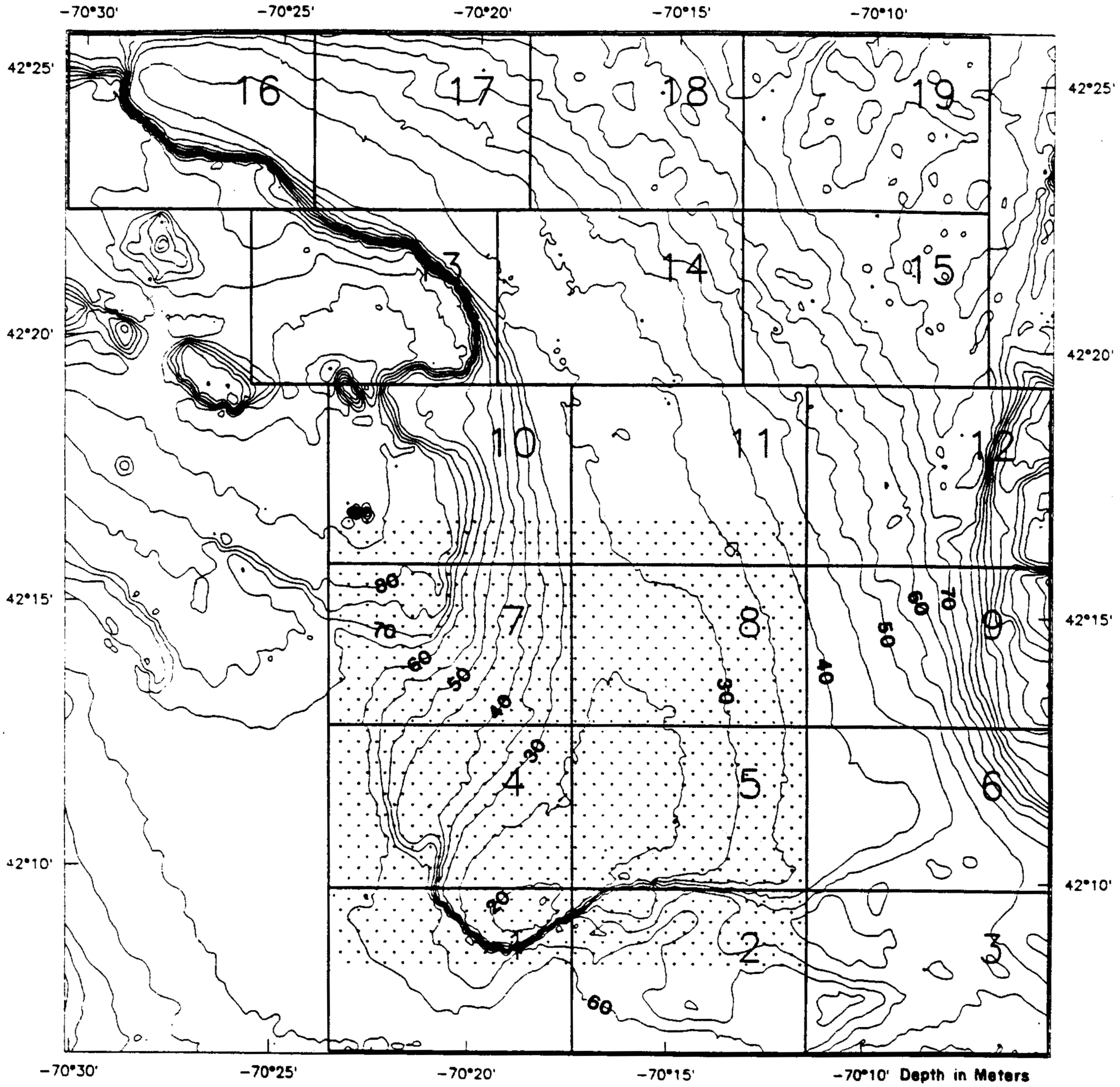

Figure 3. Map showing the topography of Stellwagen Bank and the coverage of the projected interpretive map series. Dot pattern represents the region surveyed with side-scan sonar during 1993 and that discussed in the text. Depths are in meters.

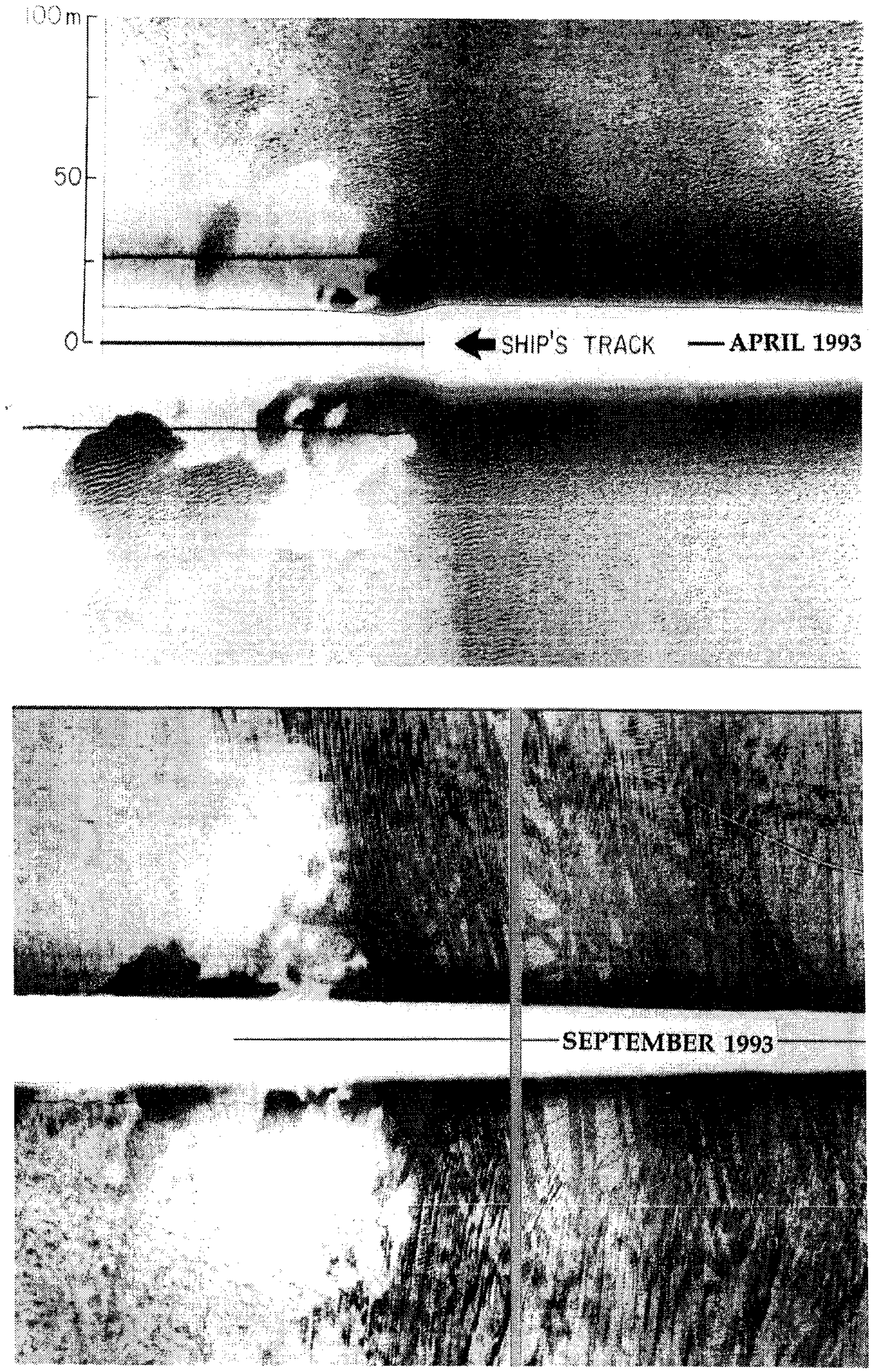

Figure 4. Side-scan sonar images (unprocessed) of the Stellwagen Bank seafloor showing the edge of a fine-grained storm sand sheet (light color) and a field of coarse-grained storm sand ripples (dark color). The upper image shows undisturbed seabed features in April 1993; the lower image shows the same area in September 1993 after disturbance by scallop dredges and groundfish trawls. Side-scan sonar frequency 100 kHz, total swath width 200 m. Depth is 32 m.

COMBINING SIDE-SCAN SONAR AND DIRECT OBSERVATIONS TO QUANTIFY RATES, IMPACTS, AND RECOVERY OF PHYSICAL AND BIOLOGICAL DISTURBANCES TO THE SEAFLOOR

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Side-scan sonar is the tool of choice for seafloor habitat mapping and surface imaging. Here, I present examples of how I have combined side-scan sonar and direct observations using scuba to quantify disturbance and related ecological patterns in a variety of soft-bottom habitats. Using side-scan sonar, I have been able to monitor and quantify the distribution, frequency, and intensity of seafloor disturbance from a wide range of natural and anthropogenic sources. These have included the physical impacts and ecological consequences of (1) ice scour in the Arctic; (2) landslides and road reconstruction along the California coast; (3) walrus and gray whale feeding disturbance in Alaskan and Canadian waters; (4) seasonal and interannual changes in habitat morphology; and (4) the characterization, distribution, and abundance of anthropogenic debris in the vicinity of McMurdo Station, Antarctica.

Side-scan sonar, combined with direct seafloor observation, is also an approach ideally suited for evaluating the impacts of bottom trawl fisheries on physical habitats and benthic communities. This issue is an important and unresolved problem in many parts of the world. Here, I present side-scan sonographs from my colleagues at Canadian Seabed Research in Halifax, Nova Scotia, Canada, which illustrate dramatic seafloor disturbance associated with bottom trawl, Danish seine, and scallop dredge fisheries on the east coast of Canada. To date, however, there has been no experimental research quantifying the long- and short-term consequences of trawling disturbance with respect to changes in (1) benthic community structure and dynamics, species diversity, abundance, distribution, and succession; and (2) physical habitat characteristics.

MUDSEIS DSP: USGS PC-BASED, HIGH-RESOLUTION SEISMIC DATA ACQUISITION

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MudSeis DSP is a U.S. Geological Survey (USGS)-developed, 2-channel, seismic data acquisition system. One or 2 channels of analog seismic data can be digitized at sampling frequencies between 4 and 5.3 kHz per channel. MudSeis DSP contains a digital signal processor (DSP) board for high-speed, 16-bit analog-to-digital (A/D) conversation and signal processing. One or 2 channels of data can be recorded as either 8- or 16-bit samples. At low shot rates (2 Hz and less), data can be recorded in either SEG-Y or MudSeis compact binary format. At ping rates up to 10 Hz, data is recorded in MudSeis compact binary format, which is easily converted to SEG-Y format using an off-line utility. MudSeis DSP employs a separate graphics coprocessor (TIMS34020) for high-performance and high-resolution (1280 X 1024 X 256) color graphics raster in real time and can also be replayed from the archive media. MudSeis DSP records to a Sony Magneto-Optical disk. Hard-copy output is produced in real time, and playback is on the Raytheon TDU-850, a high-resolution, 8-bit thermal printer.

YONAV: USGS PC-BASED INTEGRATED NAVIGATION

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YoNav is a real-time navigation and data-acquisition program written in Microsoft C/C++ that provides navigation services on almost any DOS platform. The YoNav Graphical User Interface (GUI) supports virtually any VGA and most EGA graphics hardware. In its fullest configuration, YoNav will support up to 10 simultaneous serial RS232 channels, 4 channels of digital I/O, live video display and frame capture from 3 types of video input, and graphic support for over 150 different printers. The same software will also operate on a notebook PC with only 1 or 2 serial inputs. YoNav is completely configurable by a small utility NavCfg that allows various pieces of optional hardware to be configured in or out of the system. Data can be logged in either or both a compact binary or standard USGS ASCII format on any system disk. Post-plotting of binary format navigation data can occur while data is still being acquired through a multi-tasking time-slice process.

MUDSCAN: SIDE-SCAN SONAR ACQUISITION, LOGGING, AND DISPLAY SYSTEM

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MudScan is a PC-based data acquisition and display system designed for the EG&G SMS990/996 digital side-scan sonar system. MudScan software was developed using the Microsoft C/C++ 7.0 compiler under DOS 5.0. The system architecture is based on a i486-32 mHz ISA Bus industrial embedded, PC-compatible computer using a VGA monitor for the graphical user interface (GUI) and system control. The actual sonar data is displayed with a high performance TI TMS34020-40mHz graphics coprocessor on a separate monitor.

Sonar data is acquired as a background task using a parallel I/O board and the host DMA controller. MudScan records on any DOS disk media, although optical disk has proven to be best suited to the high logging rates and large volumes of data storage required. MudScan may be used to acquire sonar data directly from the SMS996 digital modem in real time, or it may be used to display and redigitize sonar data from the EG&G SMS 960-272 analog towfish, or from the SMS 990-996 digital towfish and modem to be recorded in a computer-compatible format for later processing and enhancement. Data originally recorded on the EG&G SMS 960/Kennedy 9000 system from either the analog or digital towfish cannot be computer processed, thus the need for the MudScan acquisition and processing system. In either mode of operation, MudScan will record sonar data in the QMIPS[1] standard format that is compatible with other USGS-developed mosaicking software[2]. MudScan is fully compatible with the current USGS YoNav integrated navigation system[3]. Hard-copy sonar record output is available in real time or playback on the Raytheon TDU 850 thermal printer.

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[1] Trition Technology, Watsonville, CA.

[2] Open-File 92-XXX Sonar by Bill W. Danforth, AMG.

[3] Open File 92-565 YoNav: Your Own Navigation System by John T. Gann.

USE OF AN UNDERWATER LASER-LINE SCAN SYSTEM FOR FISHERIES APPLICATIONS

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The Laser-Line Scanner System (LLSS) is a towable underwater laser (Figure 1) capable of high resolution (mm to cm per pixel), broad swath (10–210 ft), and continuous optical surveying at speeds of 2–6 knots. Images are displayed on a video monitor, and information acquired from the system can be stored in SVHS format as well as 8-bit continuous and 12-bit "snapshot" digital data. The capabilities of the system allow "intermediate"-range surveys that complement broad-range side-scan sonar and close-range remote camera (ROV) technologies. The resolution and swath width provide an unprecedented view of the seafloor from clear to relatively turbid conditions (1 m path-length transmissivity 10-60% near bottom; Figure 2).

Although present applications of the LLSS have not focused on its use as a fishery tool, excellent results have been produced from commercial, military, scientific, and environmental monitoring applications ranging from platform abandonment to pipeline and outfall leak detection. Fisheries applications using the LLSS in a sideways-looking orientation have been used to survey nearshore kelp forest fishes off southern California. The high-resolution data produced from surveys in this configuration should allow for identification and enumeration of the various species of fish and macroinvertebrates (Figures 3 and 4). Preliminary laboratory tests have been performed using a stationary laser system to image goldfish. Use of the LLSS as a nondestructive means of sampling fish and macroinvertebrate populations, as well as surveying communities in complex habitats, is promising.

REPRESENTATIVE LASER LINE SCAN SYSTEM PERFORMANCE

Water Clarity	Typical Imaging Range	Maximum Swath Width	Area Coverage Rate (3 Knots)	Sampling Resolution (at 2048 Samples)
Very Clear (Hawaii)	45m	65m	346,000 m^2/hr	3 cm
Clear (San Diego)	22m	30m	161,000 m^2/hr	1.5 cm
Moderate (Washington State Massachusetts Bay)	9m	13m	69,000 m^2/hr	0.6 cm
Poor (Boston Harbor)	3m	4m	23,000 m^2/hr	0.2 cm

Average Resolution = 0.25 - 1.0 cm

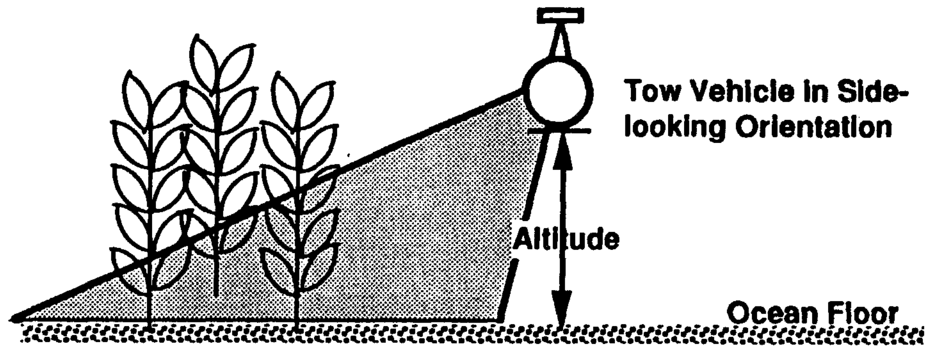

Figure 1.

ELEMENTS OF THE IMAGING SYSTEM

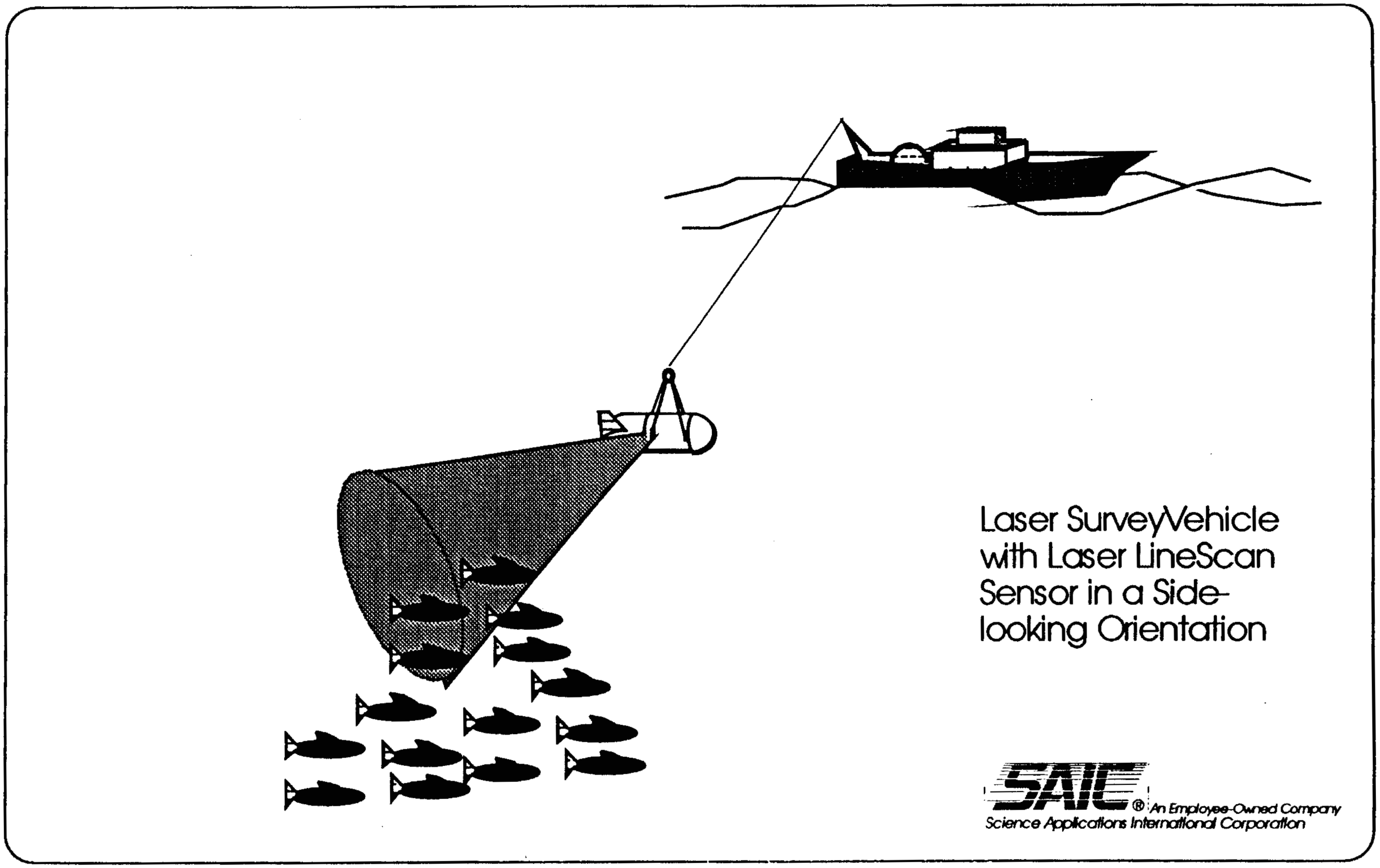

Figure 2.

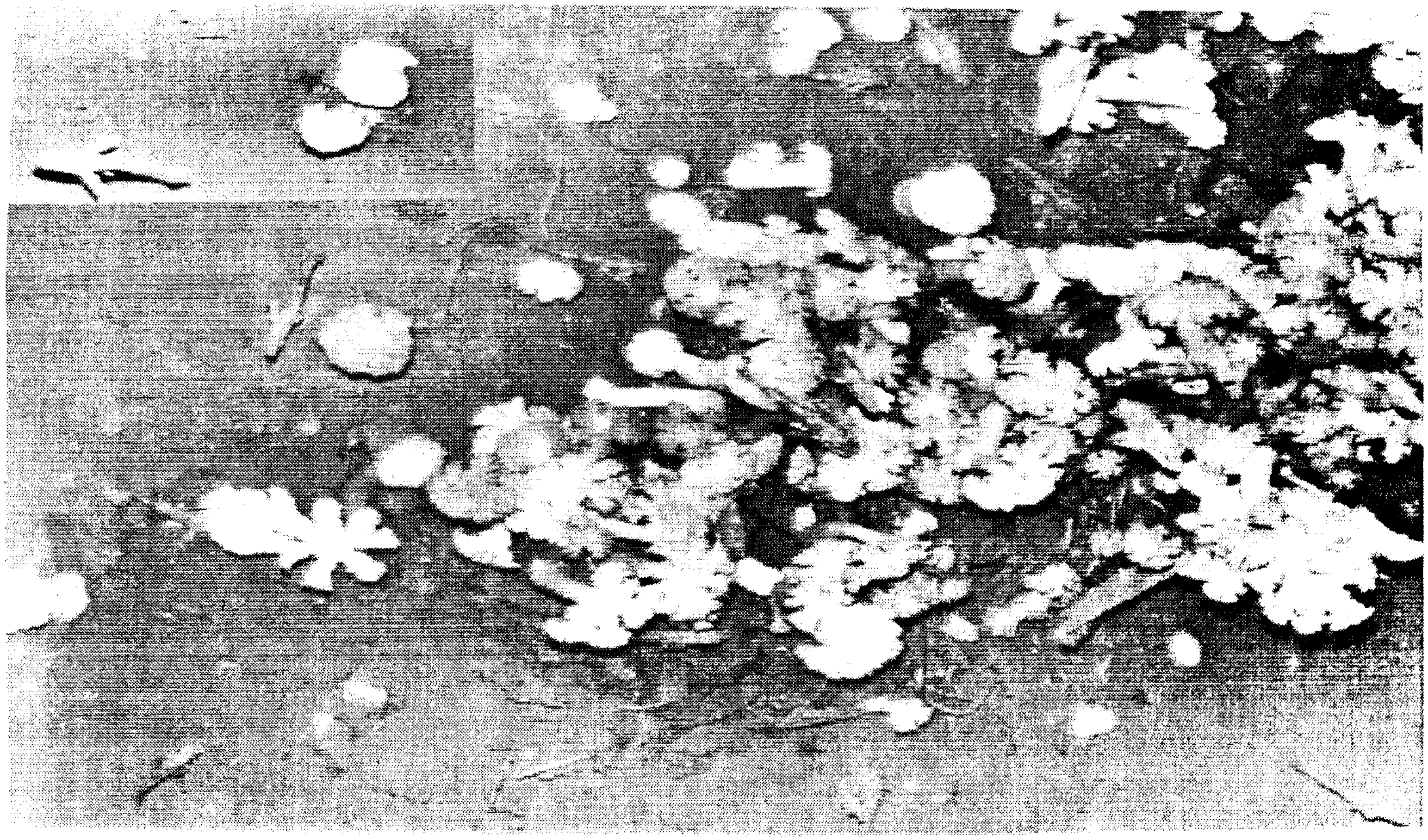

Figure 3. Debris field with growth off San Diego. These images were collected by the LLS system that was jointly developed by SAIC and ART, San Diego.

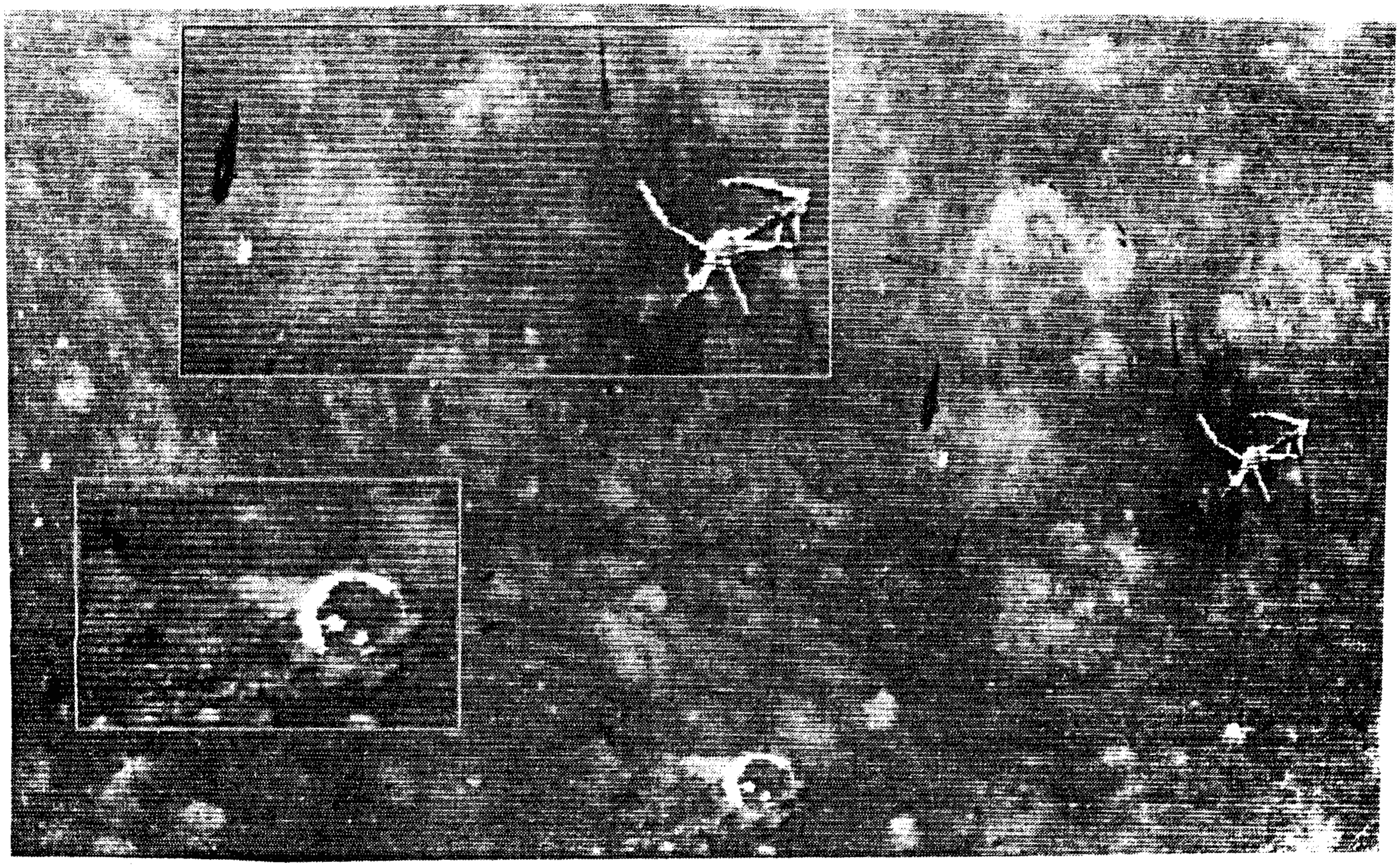

Figure 4. Spider crab near chemosythetic site in Gulf of Mexico.

THE LS-4096 LASER-ILLUMINATED UNDERWATER IMAGING SYSTEM

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A new, commercially available, field-deployable, laser-line scan underwater imaging system, the LS-4096, has recently been developed and demonstrated under a variety of rigorous operating conditions. A report has recently been published that is intended to provide the reader with a full appreciation for the current state of these developments. The report begins with a brief discussion of operational results obtained with the system during recent field trials in San Diego and the North Sea. Following this overview, the motivated reader is provided with a brief description of the LS-4096. Finally, appendices are included that provide a quantitative review of the operating envelope that can be provided by the LS-4096, along with a summary of key system specifications. A limited number of these reports are available from the author.